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SEPTEMBER 1925

PACIFIC COAST CONVENTION NUMBER

American Institute of Electrical Engineers

COMING MEETINGS

Pacific Coast Convention, Seattle, Washington, September 15-19

MEETINGS OF OTHER SOCIETIES

N. E. L. A.   New England Division, Hotel Griswold, New London, Connecticut, Sept. 8-11; Rocky Mountain Division, Hotel Colorado, Glenwood Springs, Col., Sept. 14-17; Southeastern Geographic Division, Birmingham, Ala., Sept. 15-18; Great Lakes Geographic Division, French Lick Springs, Ind., Sept. 23-26.

Association of Iron & Steel Electrical Engineers, Benjamin Franklin Hotel, Philadelphia, Pa., Sept. 14-19.

American Electrochemical Society, Chattanooga, Sept. 24-26.

American Electric Railway Association, Atlantic City, Oct. 5-9.

Association of Railway Electrical Engineers, Hotel Sherman, Chicago, Oct. 20-24.

American Welding Society, Boston, Oct. 21-23.

Illuminating Engineering Society, Hotel Statler, Detroit, Sept. 14-18.

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A National Museum
of Engineering and Industry

Monday, August 17, may prove a memorable day in the history of the four National Engineering Societies. On that day the presidents and the secretaries of these societies met Mr. Samuel Insull at a luncheon given in his honor by our ex-president, Dr. John Lieb. It was a conference luncheon, and the subject of the conference was the endeavor of founding a National Museum of Engineering and Industries. This movement started sometime ago, and recently Mr. Insull accepted the invitation to steer its course. No ship ever stranded which had him for its helmsman. The secret of his success is principally due to his good judgment in the selection of his crew. The first question which Mr. Insull addressed, very informally, to the representatives of the four engineering societies was this: Is the proposed voyage worth while, and if it is, will your societies supply me with suitable candidates for a crew? The unanimous opinion was that the voyage is worth while, and that the National Engineering Societies will gladly supply him with men worthy of the honor to serve on his crew. Your president proposed two names from the rostrum of honor of the A. I. E. E. They are ex-presidents John Lieb and Frank B. Jewett. The presidents of the other three National Engineering Societies will make their recommendations in the near future, so that the good ship will start on its voyage of exploration as soon as Mr. Insull returns from his European trip, which will be about October first. The object of this exploration will be a search for a National Museum of Engineering and Industry.

Two museums of this kind exist and have existed for a number of years; one at South Kensington, in London, and the other at Munich, Germany. Their importance cannot be overstated. He who knows the splendid influence which the Munich Museum has exerted upon the development of German Engineering and Industry cannot help wondering why a similar National Museum was not founded in the United States long ago. The project is large, but no project is too large provided its national importance is justified. In the course of a most interesting discussion the great educational power of such a museum was clearly brought out. One cannot visit the American Museum of Natural History, of New York, without being deeply impressed by its educational value. The meaning of the poet's words: "Speak to the earth and it will teach thee" is revealed there in a most impressive way. In a National Museum of Engineering and Industries one will have a splendid opportunity to speak to past generations of engineers and inventors and they will teach him. Science may be described as the study of nature's language and logic. The most concrete illustration of nature's language and logic are the structures which were created by the inventive faculty of man and developed by engineering and the industries. For instance, a properly arranged exhibit of power generators from Watt's steam engine up to the latest creations of gas engines speaks a more eloquent language than any orator ever employed, and shows a more convincing logic than one can find in any system of ancient or modern metaphysics. Address this language and this logic to the right kind of youth and watch for the results. The watching will be brief, because you will not have to wait very long for the active imagination of youth. Give the youth a chance to be thrilled by the achievements of past generations and do not rely upon books alone to produce this thrill. Put them in touch with the things which record these achievements and with the lives of men who made those things. That is the true educational mission of a National Museum of Engineering and Industry, and its importance in our national life cannot be overestimated.

It is true that a National Museum must be permanently located in some definite place, and the most natural place for it would be the National Capitol. One cannot expect every youth in this great land to make a pilgrimage to Washington for the purpose of receiving an inspiration in the proposed National Museum of Engineering and Industry. But some youth can, and the brightest of them should be encouraged to do so. Besides, why should not great centers of population like New York, Boston, Chicago, Pittsburgh, and so forth, follow the example of Washington? These centers have their museums of Natural History and of Fine Arts, and why should they not have their Museums of Engineering and the Industries? Even photographs of the treasures in these museums would have a high educational value in places which are too poor to bear the financial burden of a well equipped museum. While still a young and awkward immigrant I saw a painting in Cooper Union, New York; it was called "Men of Progress" and represented a group of inventors and captains of industry like Peter Cooper, McCormick, Mott, Morse, Goodyear, etc., whose inventions and industrial developments helped to open up the material resources of this continent. I read their lives and received a thrill which never faded.

It is not expected that the National Engineering Societies give a financial backing to this great national endeavor. Their moral support and intelligent presen-

tation of the fundamental idea underlying the enterprise is needed. If they are not interested then who can stimulate the interest of the great owners of industries and of the national legislators? The stimulus must come from the engineering professions. On this point Mr. Insull is perfectly clear. Our response to his call will be a patriotic act.

<div align="right">M. I. Pupin</div>

Some Leaders of
the A. I. E. E.

Schuyler Skaats Wheeler, the eighteenth president of the A. I. E. E., was born in New York City in the year 1860. His early training and education were gained at Friends' Seminary, Keble Hall and Columbia College.

At the age of twenty-one he left college to become assistant electrician for the Jablochkoff Electric Light Co.; later becoming identified with the United States Electric Light Co., and in 1882 joined the Edison engineering staff which had charge of the work at the first central station, introducing incandescent lighting.

Dr. Wheeler developed many of the important mechanical and electrical devices adopted during the early stages of the industry. He engineered the first stations at Fall River, Mass., and Newburgh, N. Y., for a time being stationed at the latter point as superintendent for the Newburgh Edison Company.

He was for a time electrician for the Herzog Telesme Co., and in 1886 was appointed electrician and manager for the C. & C. Electric Motor Company, the first concern established for the regular manufacture of electric motors on a commercial scale.

In the year 1888 Dr. Wheeler and Prof. F. B. Croker organized the firm of Crocker & Wheeler, which shortly was incorporated as the Crocker-Wheeler Motor Company of New York, and subsequently as the Crocker-Wheeler Co., of Ampere, N. J., of which company Dr. Wheeler remained president until the time of his death in 1923.

Dr. Wheeler was an outstanding figure in the development of electric motors; particularly in the direct application of motors to driving tools. He was electrical expert of the Board of Electrical Control, of New York, from 1888 until 1895. He was the inventor of many electrical and mechanical devices, such as the electric elevator, electric fire engine, series-multiple motor control, paralleling of dynamos, etc. He received the John Scott medal of the Franklin Institute in 1904 for the invention of the electric fan in 1886.

In the year 1900, Dr. Wheeler purchased in London and brought to America the rare and valuable collection of electrical books, pamphlets and papers gathered and owned by the late Latimer Clark, known as the Latimer Clark Library. This, the largest collection of rare electrical works in existence, Dr. Wheeler presented to the American Institute of Electrical Engineers, forming the foundation of the electrical section of the great library now housed in the United Engineering Societies Building, New York.

Dr. Wheeler was president of the Institute throughout the term 1905-1906.

A New Index of
A. I. E. E. Transactions

A new volume of the Index to the TRANSACTIONS, Volume 3, has just been completed, and includes the titles of all papers printed in the TRANSACTIONS of the A. I. E. E. from January 1, 1911 to January 1, 1922. The new volume corresponds in size with the two previous ones and completes the index of the TRANSACTIONS up to 1922, at which time the size of the annual volume was changed to 9 in. by 12 in. size.

A much more simple plan of indexing has been adopted for the present volume than was used in the earlier indexes. The topical and synoptical indexes have been replaced by a subject index, which is a very much less bulky compilation and, it is believed, will be found much easier and simpler to use. It consists of a subject index wherein the titles of papers are classified under about 75 general headings, chosen with reference to the information presented in the papers. Where more than one subject is covered in a paper the title is repeated under two or more corresponding headings. An incidental advantage of this arrangement is that the papers listed under each subject constitute a bibliography of A. I. E. E. literature on this subject for the eleven years covered by the index.

The titles under each head are arranged chronologically, and as the number of subjects is large the number of papers listed under each subject is relatively small.

The volume also includes an authors' index, in which the names of authors are arranged alphabetically and where more than one paper has been presented by the same author the titles are arranged chronologically. All discussions are listed under the authors' names with page references.

By means of this index any paper, of which the general subject or the author is known, can be readily found. Volume 3 of the index, 6 in. by 9 in., cloth, 168 pp., is sold at $2.00 per copy net.

M. I. Pupin

Doctor Michael I. Pupin, recently elected president of the American Institute of Electrical Engineers for the year beginning August 1, 1925, is the second engineer to have attained the office of president of the American Institute of Electrical Engineers and president of the Institute of Radio Engineers.

Doctor Pupin was president of the latter Institute in the year 1917. The other A. I. E. E. president who served as president of the Institute of Radio Engineers is Dr. A. E. Kennelly. He was at the head of the A. I. E. E. in 1898-1900, and of the I. R. E. in 1916.

Three-Phase, 60,000-Kv-a. Turbo Alternators for Gennevilliers

BY E. ROTH[1]
Associate, A. I. E. E.

THE Société Alsacienne de Constructions Mécaniques at Belfort, (France), installed for the Société l'Union d'Electricité, in the Gennevilliers Generating Station near Paris, three 45,000-kv-a. sets in 1922 and another in 1924. The alternators of these sets were, at the time, the largest four-pole machines ever built but they are now exceeded in power by the two new 60,000-kv-a. units, of 65,000-kv-a. overload capacity, that the Société Alsacienne is building for the Gennevilliers Generating Station. Like the 45,000-kv-a. generators, these new units are designed for delivering three-phase current at 6000 volts, 50 cycles, and run at 1500 rev. per min. direct-connected to 50,000-kw. steam turbines (Fig. 3).
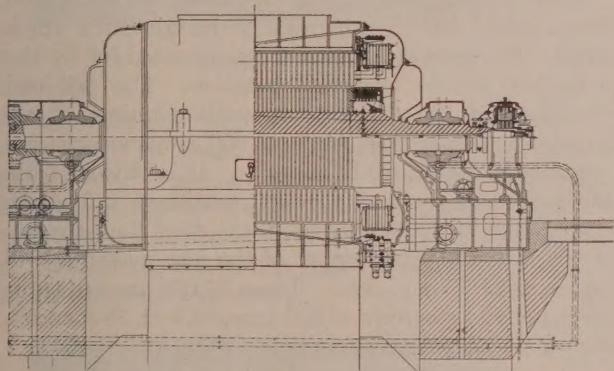
FIG. 1—LONGITUDINAL PART-SECTIONAL ELEVATION OF 60,000-KV-A. ALTERNATOR

The makers have sought to obtain the greatest strength, electrical and mechanical, in the construction of these machines, ensuring complete reliability of operation, and three years' service with the 45,000-kv-a. alternators has shown that this purpose has been fully attained. These machines have been running without incident, and tests have proved that they can even yield 55,000-kv-a. without difficulty. Indeed there have been cases where it was necessary to run them at this overload at very low power-factors. In view of these good results, it is easy to understand that relatively small modifications had to be made in the design of the 45,000-kv-a. alternators to provide the 60,000-kv-a. units. It has even been possible to make their stators and rotors interchangeable.

The detailed description of the 45,000-kv-a. alter-

nators which the author has published elsewhere[2] can thus apply to the 60,000-kv-a. units, and it seems unnecessary to repeat it here. It will be sufficient to point out, shortly, the modifications that the first alternators have undergone. However, it has occurred
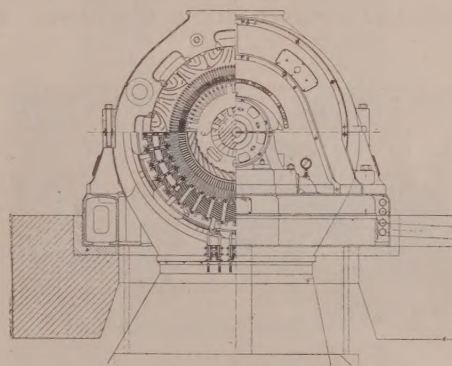
FIG. 2—TRANSVERSE PART-SECTIONAL ELEVATION

to the author that it would be interesting to reproduce in this paper, as an example of European practise, some of the photographs which have been reproduced in the
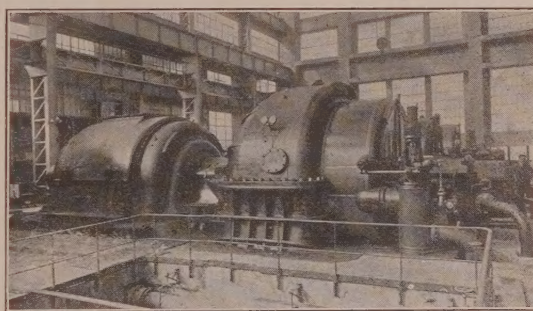
FIG. 3—GENERAL VIEW OF 50,000-KW. SET

1. Chief Electrical Engineer Société Alsacienne de Constructions Mécaniques, at Belfort.

2. E. Roth. The 40,000-kv-a. alternators built by the Société Alsacienne de Constructions Méchaniques for the Gennevilliers Power Plant of the Union d'Electricité. Revue Générale de l'Electricité 24th February 1923, Vol. XIII, page 307, and Bulletin de la Société Alsacienne de Constructions Mécaniques, No. 2, April 1923, page 42.

Large Turbo-Alternators at Gennevilliers; the 40,000-kv-a. alternators of the Société Alsacienne. The *Electrical Review* 21st and 27th April 1923, pages 604 and 646.

E. Roth. Advances in the Construction of Large Turbo-Alternators. An account delivered to the International Congress at Léige 1922 and Revue Générale de l'Electricité 27th January 1923, Vol. XIII, page 129.

papers to which reference has been made. These photographs show assembled views of the machines (Figs. 1 to 5) as well as detailed views of the stator (Figs. 6 and 7) and the rotor (Figs. 8 and 9) in the various stages of construction. But it is desired especially to call attention to some of the unusual features of these machines which may interest the American engineer, and to point out the methods and results of tests carried out on these machines.

COMPARISON BETWEEN THE DIMENSIONS OF 60,000-KV-A. AND 45,000-KV-A. ALTERNATORS

Some of the numerous heat tests made on the 45,000-kv-a. alternators are given later in this paper. At the
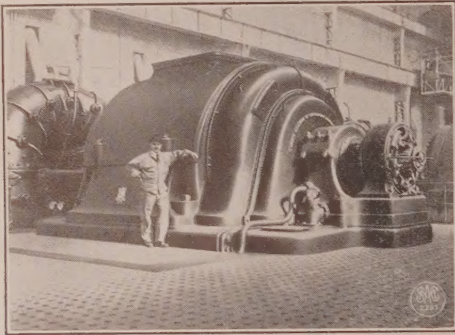
FIG. 4—VIEW OF 60,000-KV-A. ALTERNATOR

50,200-kv-a. load (Test No. VIII) it will be noticed that the temperature rise of the copper, measured by thermocouples placed on the bare copper, inside the wrappings, was but 37.5 deg. cent. while the temperature rise of the rotor copper at the same load, as
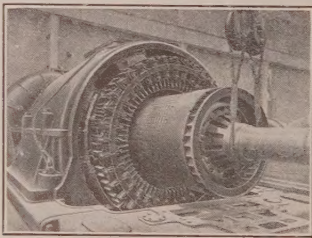
FIG. 5—ALTERNATOR IN COURSE OF ERECTION (SHOWING DETAILS OF STATOR WINDING AND CONSTRUCTION OF ROTOR)

measured by the increase of its resistance was only 67 deg. cent. although the power-factor was but 0.65. These small values of temperature rise, due to an excellent system of ventilation, have, as already stated, permitted the new machines to be given the same geometrical dimensions as the old, which have a total length of active iron of 278 cm. (Fig. 1).

The stator winding of the 45,000-kv-a. alternators was full pitch, while that of the 60,000-kv-a. units (Fig. 5) is a fractional pitch winding. The small

increase of flux made it necessary to slightly increase the section of the rotor disks by reducing the air ducts. The resistance of the latter to the passage of the air has thus been somewhat augmented; this, however, is negligible owing to the total section of the air ducts being very large.
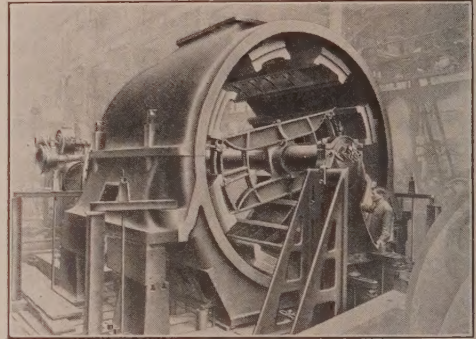
FIG. 6—BORING OF STATOR

For providing stability, the air-gap has been enlarged from 2.5 to 3 cm. The increase of the excitation which results therefrom is somewhat compensated for by the reduction of the armature reaction. The full-load excitation of the 60,000-kv-a. units requires 72,000 ampere-turns per pole while 65,000 ampere-turns are required in the 45,000-kv-a. units. It is obvious from the results of the test already mentioned and which corresponds to 75,000 ampere-turns, that the temperature rise of the rotor copper of the new machines will be less than 65 deg. cent. These 72,000 ampere-turns correspond to a current of 630 amperes with 19 conductors per slot or 114 turns per pole. (Fig. 9).
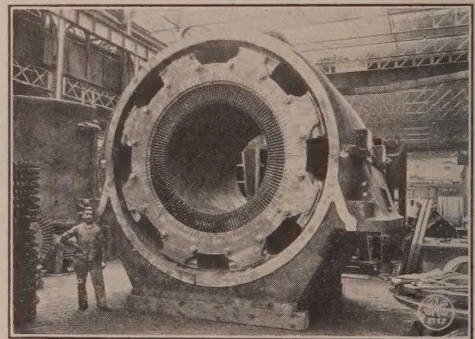
FIG. 7—COMPLETE STATOR READY FOR WINDING

Fig. 10 represents the stator slots of the two alternators and shows the proportions employed to provide for a very great leakage flux, constituting the most remarkable feature in these machines. Reference will be made to this feature later in the paper. The number of slots has not been altered but the section of the copper is slightly larger in the 60,000-kv-a. machines than in the 45,000 kv-a. units.

The bars in both machines are similarly constructed, and are made up of component conductors strongly insulated from each other and placed obliquely to the center line of the slot in order that they shall have identical positions with respect to the slot-field, (Fig. 11). The eddy current losses are thereby cut down to a negligible value. In fact, the examination of the reports of the heat test shows that the readings of the couples which are laid right on the copper (the first at the top of the lower coil side and the second at the top

Fig. 8—Rotor on the Lathe

of the upper coil side), numbered 10 and 12 in Fig. 10, are very nearly the same. In badly designed bars, the stray losses due to eddy currents are very much greater in the upper conductor of a slot than in the lower. The fact that the temperature rise of both conductors is the same leads to the conclusion that the supplementary losses are completely eliminated.
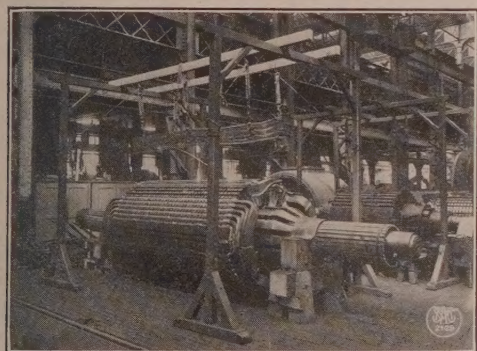
Fig. 9—60,000-Kv-a. Rotor Being Wound

The dimensions of the air-cooler, a description of which has already appeared in the papers mentioned, have been somewhat enlarged. It will be recalled that the air describes a closed circuit. It is cooled by means of an air-cooler wherein the condensate circulates and which possesses the interesting characteristic that the amount of cooling water is maintained greater than a given minimum whatever the load may be. Thus a certain part of the water returns to the condenser immediately after leaving the air-cooler. This arrangement was made to overcome the difficulty of the

losses in turbo-alternators being but slightly variable with the load, whereas the amount of condensed water essentially depends thereupon; hence, a risk of over-heating the air at light loads if the condensate alone is employed for cooling.

The total weight of the 60,000-kv-a. alternator is 162 metric tons, (356,400 lbs.) without bearings and base-plate. The stator alone weighs 104 tons, the rotor, with the exciter, 50 tons, and the end-shields, 8 tons. It may be interesting to compare these weights with

Fig. 10—Showing Arrangement of Thermo-Couples

a
45,000 Kilovolt-amperes

b
60,000 Kilovolt-amperes

Stator Slots

those stated by Messrs. Foster, Freiburghouse and Savage in their paper on *"Large Steam Turbine Genera-tors,"* JOURNAL of the A. I. E. E., October 1924, page 923. For a 62,500-kv-a.; 1200-rev. per min., 60-cycle turbo-alternator, these authors give the following weights: stator, 93 tons without bearings and base-plate; rotor, 93 tons; end shields, 11 tons,—giving a total weight of 197 tons. The differences in weight are easily explained by the fact that the Société Alsa-cienne's alternator is a four-pole machine while the alternator described by those authors is a six-pole machine.

CONSIDERATION OF THE ADVANTAGE OF EMPLOYING
LEAKAGE SLOTS

The leakage slots (Fig. 10) are the most interesting eature in these machines. They serve a double purpose since they first artificially increase the leakage for the stator, thus reducing the instantaneous short circuit current to a very low value; and then serve

advantageously as a channel for the cooling air. These two functions of the leakage slots will be examined in detail and it will be seen that the latter is by no means the least important.

The design of these machines has been largely influenced by the condition that, without the use of reactance coils, the instantaneous value of the symmetrical short-circuit current should not exceed four to five times that of the normal currents. The actual values are 4.17 for the 45,000-kv-a. alternator and 3.7 for the 60,000-kv-a. units. To obtain these exceptionally low values, special arrangements had to be employed.

It is a well-known fact that the instantaneous short-circuit current in turbo alternators is almost solely limited by the stator leakage for, not only is the rotor
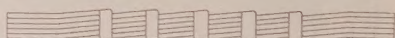
leakage very small, but its effect is still further reduced by the presence of dampers. Therefore, neglecting the rotor leakage, the above mentioned values of the instantaneous short-circuit current in the 45,000-kv-a. and 60,000-kv-a. alternators correspond to respective inductive drops equal to 24 per cent and 27 per cent of the normal pressure with the normal current. But it is not recommended to obtain these high inductive drops by the usual means consisting of designing an alternator with a high armature reaction, because, as will be seen later on, serious disadvantages could result in the course of operation. But let us first examine the conditions which must be fulfilled in the dimensioning of the leakage slots and their advantages to the alternator itself.

The height of these slots may occasion surprise, since the same inductive drop could, in fact, be obtained by means of much smaller slots. Thus the supplementary leakage obtained by the leakage slots is the same in a and b of Fig. 12. But it should be borne in mind that on a short-circuit the normal path offered to the flux is checked and that the major part of the flux is obliged to seek its way across the slots. It is necessary, therefore, that the depth of the leakage slots be sufficiento avoid saturation of this path, since the magneto, motive force, and thus the short-circuit current which produces it, would be increased due to saturation.

The following table shows how the inductive voltage drops caused by stator leakage are distributed in both machines; these figures are stated in per cent of the normal voltage for the normal current.

	45,000-kv-a. Alternator	60,000-kv-a. Alternator
Normal slots	2.8 per cent	4.1 per cent
End connections	9.5 per cent	12.0 per cent
Zig-zag leakage	1.5 per cent	1.9 per cent
Leakage slots	10.2 per cent	9.0 per cent
Total	24.0 per cent	27.0 per cent

Therefore, on a sudden short-circuit, the flux which, passes across the leakage slots in the 45,000-kv-a.

alternator is $\frac{10.2}{24}$ or 42.5 per cent and, depending on the instant of the short-circuit, even twice this value, or 85 per cent of the normal flux. In the 60,000-kv-a. alternator, the corresponding values are $\frac{9}{27}$ or 33 per cent and can reach twice this value, or 66 per cent of the normal flux.

Owing to these values being smaller in the 60,000-kv-a. machines, it has been possible to reduce the height of the leakage slots (Fig. 10) and thus increase the height of the core back of the slots with the same magnetic density in the core of both alternators, notwithstanding the greater total flux in the 60,000-kv-a. design.

Advantages of the Leakage Slots with Regard to the Alternator. It may be contended that these high teeth cause an increase of the losses in the teeth, but this possibility is easily compensated for by very slightly increasing the weight of the copper. And here the first advantage of these slots appears, in that they permit a greater weight of copper to be placed on the stator than that corresponding to the diameter of the bore. This greatly facilitates the construction of very powerful alternators.

a   b
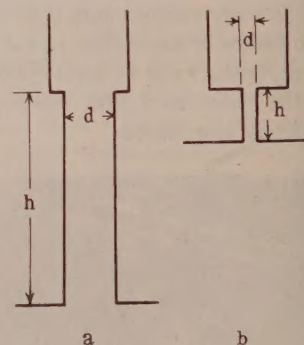
Fig. 12

Another advantage resulting from the leakage slots may be described as follows. The important point on short-circuit is not the actual value of the instantaneous current, but the stresses exerted on the end connections. But these stresses are weaker at equal short-circuit current, when the reactance is produced by increased slot leakage. In fact, in alternators where the stator leakage is obtained by a high armature reaction, the major part of the leakage is due to the end-connections. It is consequently necessary that on short-circuit these should withstand the dynamical stress due to a flux nearly equal to the normal flux or, depending on the instant of short-circuit, to even twice this flux. Now in the case of the 45,000-kv-a. alternator the flux that, on short-circuit, is interlinked with the end-connections,

is but $\frac{9.5}{24}$ or about 40 per cent, and in the worst

conditions 80 per cent of the normal flux. In the case of the 60,000-kv-a. units, this value becomes $\frac{12}{27}$ or 44.5 per cent, and a maximum of 89 per cent. Furthermore, in machines with high armature reaction, the weight of copper to be placed in the end-connections is much greater than in a machine with a small armature reaction, and consequently, the involutes are longer and more difficult to secure and higher stress must be withstood by a part less capable of withstanding it.

We have already stated that the leakage slots perform an important function in the ventilation of these machines; reference to this will be made later.

Advantages of the Leakage Slots with Regard to the Operation. Having pointed out the advantages of the leakage slots with reference to the alternator itself, we will now examine the advantages they present with regard to operation.

One important condition with which the alternators have to comply relates to *stability of operation*, which requires a high pull-out torque; the alternator should not tend to hunt or run out of step under an accidental overload. The condition of stability is generally complied with when the machine operates on a system having a certain inductive reactance, but it is more difficult to satisfy when it may be called upon to supply a system with a capacitive load or even when the power-factor is not much different from unity. Now, when the limiting instantaneous short-circuit current imposed is low, the required stability may be attained with an alternator having a high armature reaction, or, in other words, owing to stability refinements it may become impossible to design the alternator for the short-circuit current imposed. In this case, compliance with the conditions of stability leads to the design of an alternator with a rather high flux, and to the artificial increase of the leakage by means of special slots so as to obtain the proper value of the instantaneous short-circuit current.

But a small armature reaction is also necessary when it is desired to avoid *self-excitation*. This question is of sufficient importance to be dealt with in the special section following. We shall see that in this further particular, the leakage slots are extremely useful.

The Auto-Excitation of Turbo-Alternators

It is known that in certain conditions an alternator, when switched on to a capacity, may be self-exciting; that is, it may proceed to function as a generator, its magnetizing current being supplied by the capacity. This phenomenon has been described many times[3]

especially by American engineers. These studies show that an alternator will be less self-exciting the larger the air-gap and the smaller the armature reaction.

Synchronous Self-excitation of Alternator with Salient Poles. Messrs. Blondel[4] and Bethenod[5] have shown that an alternator, when connected to a capacity, may be self-exciting under certain conditions if the reluctance of the path offered to the flux of direct reaction is different from that offered to the flux of transversal reaction. The current produced is at a frequency synchronous with the pulsation. We call this phenomenon "synchronous self-excitation." This difference between the reluctances of the paths of the two fluxes of reaction always exists in salient-pole alternators, but it is not so marked, being sometimes absent altogether, in turbo alternators. The synchronous self-excitation cannot therefore generally take place in these machines, and is even absolutely impossible when the rotor teeth are uniformly distributed over the periphery of the rotor.

Asynchronous Self-Excitation of Turbo-Alternators. In this case, however, another kind of self-excitation may take place, but it is necessary that the rotor be provided with dampers or the rotor winding be a closed circuit. The frequency of the current produced by the machine is no longer synchronous with the pulsation when the field does not revolve synchronously with the rotor, and obtains a certain slip with regard to it. This phenomenon which we have called "asynchronous self-excitation" has been studied by Mr. Bethenod[6], who pointed out the danger it would present to turbo-alternators.

The conditions of self-excitation, whether synchronous or asynchronous are the same; the main cause is the residual magnetism. The self-excitation may in general be explained as follows:

rendu des trauvaux de le 1° Conférence internationale des Grands réseaux 1921, p. 881.

J. Bethenod. Sur l'alternateur à résonance. La Lumière electrique, 25th December 1909, Vol. VIII, p. 398.

F. D. Newbury. The Behavior of Alternators with Zero Power-factor Leading Current. The *Electric Journal* 1918, p. 363.

R. W. Sorensen, H. Cox and G. E. Armstrong. California 220,000-volt, 1,500,000-kw. transmission bus. Proceedings A. I. E. E. 1919, Vol. XXXVIII, p. 1027.

W. O. Morse. The Behavior of Alternating-Current Generators when Charging a Transmission Line. *General Electric Review*, Feb. 1920, Vol. XXIII, p. 109.

C. J. Fechheimer. Transactions A. I. E. E. 1920, Vol. XXXIX, p. 1637.

G. Darrieus. Les réseaux de distribution et la transmission à trés haute fréquence. Exemples Américains. Bulletin de la Société francaise des Electriciens 1920, Vol. X, p. 411.

T. Labouret. Répercussion des lignes de forte capacité à vide nu le fouctionnement des alternateurs. Revue générale de l'Electricité, 17th December 1921, Vol. X, p. 875.

3. P. Boucherot. Alternateurs Auto-excitateurs. Bulletin de la Société Internationale des Electriciens, Feb. 1898 Vol. XV, p. 79.

A. Blondel et Ch. Lavanchy. Rapport sur les réactions d'un réseau à haute-tension sur l'excitation des alternateurs. Effets de résonance et d'auto-amorçage sous charge réduité. Compte-

4. loc. cit.

5. loc. cit.

6. T. Bethenod. Auto-amorcage des machines, à rotors cylindriques associées à des condensateurs. Revue générale de l'Electricité, 8 September 1923, Vol. XIV, p. 307.

When starting an alternator connected across a condenser, the residual magnetism induces in the alternator a very small electromotive force. This, owing to the presence of the condenser, produces a current leading by $\frac{\pi}{2}$ which adds its magnetizing action to that of the residual magnetism. However, this effect can start the auto-excitation only at the speed by which the capacitive reactance of the condenser is slightly higher than the inductive reactance of the alternator. In fact, from this time on, the current in quadrature with the electromotive force is sufficient to magnetize the machine. As the pressure builds up, the current does likewise, one boosting the other, the phenomenon being limited only by the saturation of the alternator.

But any condenser has losses however small they may be. Losses are also developed in the iron and copper of the alternator due to the passage of current, and these losses can be even higher than the normal losses. As the corresponding active power can be derived only from the motor driving the alternator, an electromagnetic torque has to be developed between the stator and the rotor.

The existence of this torque is rendered possible in two ways,—in the salient-pole alternators, by the dissymmetry of the magnetic circuit in which case the self-excitation is synchronous, and in the turbo-alternators, by the presence of a damping circuit or the closed field circuit. In the latter case, the self-excitation is asynchronous; in fact, an active component of the current in the stator requires the presence of a corresponding component in the rotor winding for the production of which an electromotive force is required, and in order that it may be induced, it is necessary that the speed of the rotor be different from that of the revolving field, the rotor leading with regard to the field by the speed of the slip. Therefore the conditions of the existence of this component of the current in the rotor are the same as the conditions of existence of the current in the induced winding of an asynchronous generator.

The condenser is practically represented by the line which has but a small resistance. The value of the slip is then very small so that the frequency of the alternator running under the conditions of asynchronous self-excitation is not, at the normal speed, much different from the normal frequency; hence it ensues that the conditions of asynchronous self-excitation and of synchronous self-excitation are the same. The alternator is self-exciting when the capacitive reactance of the line is slightly superior to the inductive reactance of the alternator, the limiting case being that where the characteristic of the line coincides with the straight part of the no-load characteristics of the alternator.

Formula Useful in Ascertaining the Conditions of Self-excitation. The conditions of self-excitation just stated can be expressed in a very simple form. On examination of the no-load and short-circuit characteristics

of an alternator, determines whether self-excitation will take place in the case of a line of, say, L km. length.

Study of a certain number of high-voltage three-phase lines indicated that their capacitive reactances did not vary much from one line to another and that the value, per phase, (whatever the pressure) is, for 50-cycle lines, about 0.385×10^6 ohms per km. It is therefore approximately correct to multiply the value of the line pressure U, per phase, by the reciprocal of this capacitive reactance and by the length, L, in km., to obtain the charging current of the line, or:

$$\frac{10^{-6}}{0.385 \sqrt{3}} \times L \times U = 1.5 \times L \times U \times 10^{-6} \text{ amperes.}$$

Multiplying this value by the transformer ratio gives the value of the charging current in the line, corrected to the pressure U_a of the alternator. It becomes

$$I = 1.5 \times \frac{U^2}{U_a} \times L \times 10^{-6} \text{ amperes.}$$

According to what has just been stated the self-excitation will take place when the magnetizing current supplied by the line is slightly higher than the current necessary for exciting the alternator. Therefore, by reading, on the extension of the straight part of the no-load characteristic of the alternator, the number of ampere-turns corresponding to the value U_a, of the normal voltage of the alternator, and determining the armature current, I_a, on the short-circuit characteristic corresponding to the same number of ampere-turns, the self-excitation takes place when

$$I > I_a$$

or when

$$1.5 \frac{U^2}{U_a} \times L \times 10^{-6} > I_a \text{ amperes.}$$

Application of Formula to the 60,000-kv-a. Alternator. The full lines on Fig. 13 represent the no-load and the short-circuit characteristics of the 60,000-kv-a. alternator. It will be noticed that a current $I_a = 2400$ amperes on the short-circuit characteristic corresponds to the normal pressure of 6000 volts read on the straight part of the no-load characteristic. Assuming a three-phase line at $U = 150,000$ volts at 50 cycles, self-excitation will take place when the length, L, of the line is such that

$$L \times 1.5 \times \frac{150,000^2}{6000} \times 10^{-6} > 2400 \text{ amperes.}$$

or

$$L > 426 \text{ km.}$$

Let us now compare this alternator with another of the same kv-a. output, but without leakage slots; one which also has to comply with the condition that the instantaneous short-circuit current be 3.7 times the normal current, corresponding to 27 per cent inductive

drop due to the stator leakage. As it is constructed, the leakage slots of the alternator produce 9 per cent inductive drop. Suppressing these leakage slots will give a total drop of only

$$27 - 9 = 18 \text{ per cent.}$$

It is therefore necessary that the alternator without leakage slots be designed with a sufficiently higher number of conductors to increase the reactance from 18 to 27 per cent. As the inductive drop increases as the square of the number of conductors, the numbers of conductors on the stators of the two machines should be in the ratio,

$$\sqrt{\frac{27}{18}} = 1.225$$

The flux in the second machine is reduced in the same ratio. There being imposed the supplementary condition that the magnetic circuits of both alternators be identical and all parts be submitted to the same induction, it ensues that their lengths should be in the ratio of these fluxes. Therefore, the length of the active iron of the alternator without leakage slots becomes

$$\frac{278}{1.225} = 227 \text{ cm.}$$

The copper on the periphery of the rotor of the second machine will have the same section and will then be capable of developing a magnetomotive force corresponding to 72,000 ampere-turns. Constructing the Potier's diagram for this new alternator shows that this total number of ampere-turns can be maintained only when the armature reaction is increased by 22.5 per cent by reducing the air-gap from 3 to 1.64 cm. But it is very possible that an alternator so designed will be unstable.

The no-load and short-circuit characteristics of such an alternator are traced in dotted lines on Fig. 13. Applying the above stated rule, it will be found that the self-excitation will take place if the length, L, of the line be such that

$$1.5 \times \frac{150,000^2}{6000} \times L \times 10^{-6} > 1140 \text{ amperes.}$$

corresponding to a line of

$$L > 202 \text{ km.}$$

This shows that with an imposed instantaneous short-circuit current of, say, 3.7 times the normal current, the alternator with leakage slots is self-exciting when the length of the line exceeds 426 km. while the one without leakage slots is self-exciting when the length of the line is only 202 km. This important advantage is obtained by a relatively slight increase of the length of the active iron, from 227 to 278 cm. Let us further add that the alternator without leakage slots becomes unstable, also that in spite of an equal short-circuit current, the end connections are stressed twice as much as those of the alternators with leakage slots and that, finally, it be-

comes very difficult to place the copper on the periphery of the stator.

VENTILATION OF 45,000-KV-A. AND 60,000-KV-A. ALTERNATORS

The ventilating air of the rotor follows two courses: One part enters the holes in the plates supporting the fans (Figs. 1) passes into the end-connections and escapes by the notches cut into the end-plates of the rotor, as shown in Figs. 5, 8 and 9.

The other part enters the rotor by conduits cut into the shaft (Figs. 1 and 5); thence is distributed to the air ducts, from which it passes into the air-gap and is expelled through some of the air ducts of the stator, (Fig. 7) thus contributing to the cooling of the same and is finally discharged into the frame. Therefore, the cooling air follows a radial path passing through the rotor at a rate of from 13 to 14 cubic meters per second.

We have already pointed out the importance of the leakage slots to the ventilation of the stator, as performed in the following manner. Each fan situated at the ends of the rotor, delivers from 18 to 19 cubic meters per second, draws the air into the end-shields, where it penetrates between the end-connections. These latter are particularly well cooled, because of a definite spacing maintained between the involutes, permitting the air to circulate freely around them.

From the end-shields, the air enters by channels arranged in the frame (Fig. 6) and is distributed to the stator ducts. (Fig. 1). A certain amount of this air cools the core on its way across the ducts and passes into the frame; but the major part of the air penetrates between the teeth, then circulates axially in the leakage slots and follows the reverse path in the next duct, from which it also passes into the frame.

These various paths of the air and the air guide baffles may be seen in Fig. 2. It should be understood that the baffles of one type which guide the air at the intake are situated along the entire air duct and those of another type to guide the air at the exhaust, are arranged all along the next air-duct.

This system of ventilation may, in a certain manner, be compared with that described by Mr. Fechheimer, in his paper[7]; but two essential differences exist between the two systems. First, in that of the Société Alsacienne, the air flows axially not in the air-gap but in the leakage slots, the air-gap being, as already stated, a collector for the air of the rotor. The leakage slots are very close to the conductors and afford a much greater surface for the transmission of heat than the air-gap. The second point which distinguishes the two systems lies in the fact that in the one described by Mr. Fechheimer the air of several air ducts is discharged by a corresponding number of other neighbour-

7. *An Experimental Study of Ventilation of Turbo Alternators.* JOURNAL of A. I. E. E. May 1924, page 416, Fig. 23.

Also see: Dr. Bratt. *The Multiple Radial System of Cooling Large Turbo Generators.* JOURNAL of A. I. E. E. March 1924, page 185.

ing ducts, while in the system described herein, the air flowing across an air duct passes in a reverse direction in the next two. The speed of the air in the leakage slots is therefore small.

This arrangement has consequently all the advantages of the axial ventilation without the inconveniences of producing very high temperatures at the center of the machines, the cooling air being distributed uniformly

mentally by tests carried out on the apparatus as represented in Fig. 14.

MEASUREMENT OF THE TEMPERATURE RISE

The heat tests to which the alternators have been subjected are also reported in Table I. One short-circuit test (No. I); one no-load test, with no-excitation, which gave the temperature rise due to the venti-

TABLE I

Test No.	I	II	III	IV	V	VI	VII‡	VIII‡
Nature of Test	On short circuit	No load not excited	No Load			On Load		
Voltage V................	..	..	6000	4800	5400	5350	5610	5820
Current A................	4800	..	..	4450	4200	4600	4600	5000
Load Kw..........	..	..	..	22,500	26,500	32,500	32,000	32,800
Kv-a.........	..	..	..	37,000	39,300	42,700	44,600	50,200
Power factor.............	..	..	..	0.61	0.70	0.765	0.72	0.65
Exciting current A.........	310	..	136	415	430	432	455	545
Position and Indication of the Couples*	Increase of temperature above the temperature of the intake air, deg. cent.							
Core M..................	25	7	39	42.5	44	45.5	49	52
" L.................	18	4.8	31.5	28.5	34	29.5	31.5	34.5
" K.................	17	6	30.5	27.5	29.5	30	28.5	31
Teeth G.................	70	9	24	47.5	56.5	53.5	54.5	60.5
" D.................	44	10	22	38.5	38	40.5	39.5	46.5
" F.................	27	8	26	32.5	34.5	33.5	33.5	36.5
" E.................	26	8	23	30.5	30.5	32	27.5	29.5
Between A............	47	9	20.5	35.5	37.5	37.5	39.5	46.5
Wrappings B............	32	10	26	32.5	31.5	†	36.5	40.5
" C............	27	9	23	23.5	25.5	†	23.5	27.5
On the copper 10.......	40	12	26.5	33.5	32.5	33.5	31.5	37.5
In the slot 12.......	41	12	27.5	33.5	33.5	32.5	31.5	37.5

*The indications of the couples correspond to those given in Figs. 10 and 15.
†Couple art.
‡Tests Nos. VII and VIII were not carried out on the same group as Nos. I to VI.

along the whole length of the laminations. The heat tests are the best proof of the efficiency of this system of ventilation. One will notice the fairly uniform value of the temperature rises along the whole length
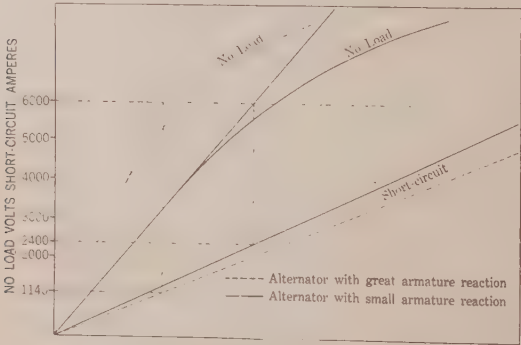

FIG. 13

of the stator read during the test No. III (Table I), where the alternator, excited at the normal voltage was submitted to a no-load heat test.

The necessary air pressure was determined experi-
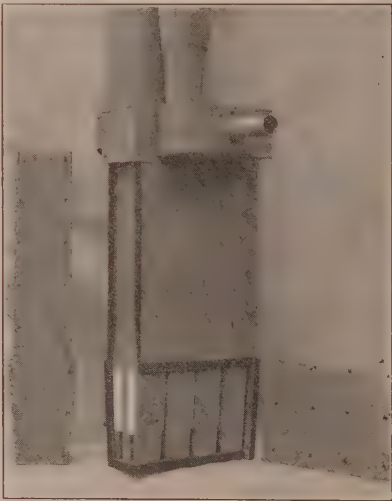
FIG. 14—DEVICE FOR MEASURING PRESSURE OF COOLING AIR

lating air (No. II); the test No. III already mentioned and a number of tests at various loads and various power-

factors have been carried out, of which the tests No. IV to VIII have been reported.

The temperature rise of the rotor was determined by the measurement of the increase of the resistance; that of the stator by means of thermocouples. Many of these were installed throughout the stator, most of them during the construction; thus couples have been laid within the laminations in the core and in the teeth when piling up the plates. Two couples were embedded right on the copper inside the wrappings in the middle of the bars. Care was taken to connect the bars directly to neutral in order to avoid all danger during the reading.

In almost every case the couples were laid in duplicate, one serving as a spare to the other in case of breakage. The location of the couples is indicated in Figs. 10 and 15. With regard to the iron, the tables make a distinction between the couples in the core and those in the teeth, also for the measurement of the temperature of the copper by couples between the wrappings and on the bare copper.

MEASUREMENT OF THE LOSSES AND THE EFFICIENCY[8]

This article by the author contains data with regard to the efficiency of alternators at various loads. Tests have been carried out in order to measure the amount of the air by means of an anemometer and the temperature

FIG. 15—ARRANGEMENT OF THERMOCOUPLES (SEE FIG. 10)

rise by means of thermo-electric couples laid at the inlet and at the exhaust of the air of the alternators. As the air circulates in a closed circuit the air chambers are not easily accessible, hence the measurement of the air speed by means of the anemometer is rather difficult. For this reason, the Société Alsacienne has elaborated the following method which has confirmed the accuracy of the first measurement. It will be an interesting matter to discuss.

Various methods have been proposed which obviate the necessity of measuring the amount of air[9]. Of these we shall mention the following: a. When it is possible to measure the losses p_0 in any running conditions at (no-load, for example), these losses are measured, as well as the temperatures t_0 at the intake and t_1 at the exhaust of the air. At the contemplated load the temperatures t_0' and t_1' of the air at the intake and the exhaust are also measured. The total losses of the

8. E. Roth and G. Belfis. The Measurement of Losses in Totally Enclosed and Ventilated Electrical Machines, Specially the Turbo Generators. Bulletin de la Société Alsacienne de Constructions Mécaniques, No. 9, January 1915, page 20.

9. S. F. Barclay. The Determination of the Efficiency of the Turbo Alternator. The JOURNAL of the Institution of Electrical Engineers. August 1919, page 293.

machine at the considered rating will be

$$p = p_0 \frac{t_1' - t_0'}{t_1 - t_0} = p_0 \frac{\Delta t}{\Delta t_0}$$

b. It is also possible to install in the path of the air a heating resistance with which to calibrate the system. The power consumed by this resistance taking the place of the measurable losses p_0 mentioned in the first method, the total losses will be determined as indicated above.

It is obvious that these methods of measurement apply not only to the turbo alternators but also to any totally enclosed and ventilated machines. They can easily be employed on the test stands, but they often meet with certain difficulties when it is necessary, as is very often the case, to apply them to machines already erected. With particular regard to the method under the heading (b), it is easy to see that installing a heating resistance across the air channel is difficult; and it does not give the desired result because the heating is not produced at the same places as on normal running. In the method described under (a), on the contrary, the known losses, which serve for the calibration of the system are produced within the machine, and for this reason this method should be preferred to the other one whenever applicable. However it also presents certain difficulties when it is desired to employ it for the measurement of the losses in machines already installed.

It often occurs that the no-load losses of the machine can be measured at the test stand where it is impossible to make a test under load. With these conditions, the method (a) is applicable to the machine when installed. The temperature rise corresponding to the known losses is first measured, the losses on load being deduced conversely from the temperature rise of the air. But when the machine is of such dimensions that the no-load test on the test stand is impossible, this method cannot be employed directly. This is particularly the case with the large turbo alternators. In order to measure in this case the known losses p_0 in the machine and to determine in a precise manner the temperature differences, the following method has been devised which is particularly applicable to machines the ventilation of which is performed in a closed circuit.

Calibrating the System. The known losses in an alternator may be determined by running it as a synchronous motor, but the power consumed by the latter includes not only the losses which contribute to heat the cooling air but also the friction losses in the bearings to which the losses in the driving motor, (a steam turbine, for example) should be added when care has not been taken to disconnect it. However two tests permit these constant losses to be eliminated, the alternator being run as a synchronous motor at two different voltages, the one e_2 as high and the other e_1 as low as possible. The constant temperatures being attained in each case, the temperature rises Δt_2 and Δt_1 of the air are measured, as well as the powers consumed p_2

and p_1. For a power $p_2 - p_1$ consumed in the machine, the temperature rise of the air would be therefore $\Delta t_2 - \Delta t_1$ and one may conclude conversely that, under the same running conditions as to rate of air flow, for which the temperature rise of the air would be Δt, the losses will be

$$p = (p_2 - p_1) \frac{\Delta t}{\Delta t_2 - \Delta t_1}$$

In order that the powers p_2 and p_1 may be accurately measured, it is advantageous to adjust the excitation to reduce to a minimum the current input.

Measuring of temperature rises. It is easy to understand that the value of the method will depend upon the
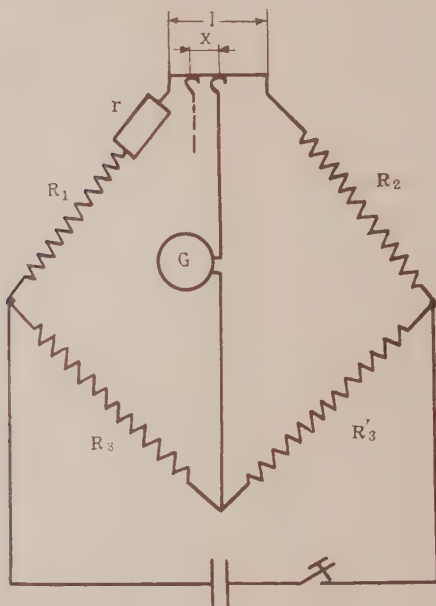
Fig. 16

accuracy with which the power and the differences of temperature, Δt, are measured. The industrial watt-meters permit of an approximation of 0.8 per cent; it will be seen later that, thanks to the test method adopted, the differences of temperature can be measured with such exactness that the accuracy of the method depends almost solely upon that of the wattmeters.

The temperatures can be measured by three different means; the thermometer, the thermoelectric couples, or the variation of the resistance of a metallic wire.

The thermometer is to be excluded from all methods of high precision; furthermore it is difficult to handle as the apparatus for the measurement of the temperature must be installed at places highly inaccessible during the tests.

Thermocouples could be employed, but these devices also do not afford as high a precision as the method based upon the measurement of the increase of the resistance of metallic wires. It is a known fact that measurements of resistance are the most precise meas-

urements in electrotechnics and even in physics, in general. This last method has, therefore, been selected. It has the further advantage of greatly simplifying the measurements owing to the fact that the increase of the resistance of a metallic wire in terms of the temperature
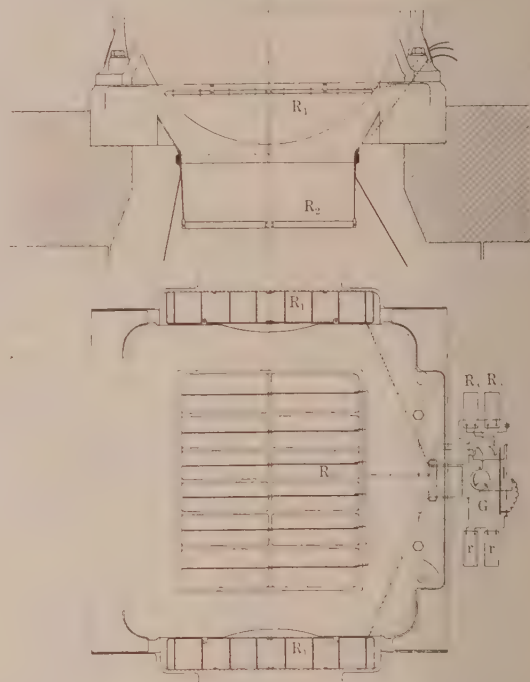
Fig. 17—Arrangement of Resistances and Apparatus for Measuring Efficiency

follows, at least in the limits that interest us, a rigorously linear law, which is not the case for the electromotive force of a thermocouple.

The variation of the resistance of a metallic wire is measured by means of a Wheatstone bridge. Direct measurements for the differences Δt between the tem-
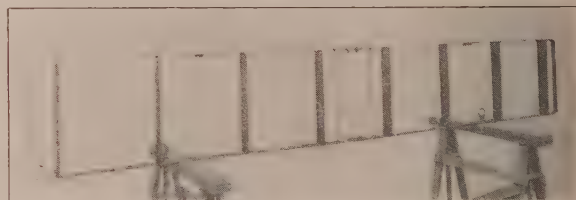
Fig. 18—One of the Two Resistances R_1 Placed in Air Entrance

peratures at the intake and the exhaust of the air are made, rather than measuring these temperatures separately. To this end, two resistances, R_1 and R_2, forming the two arms of a Wheatstone bridge (Fig. 16), are placed respectively at the intake, and the exhaust of the air R_1 and R_2, have equal resistances at equal temperatures.

As the temperature varies somewhat from one part of the section of the air conduit to another, the resistances R_1 and R_2 are placed so that their elements are uniformly distributed over the whole section of the conduit; the difference of the average temperature is thus directly measured (See Figs. 17 and 18).

Two other resistances, R_3 and R_4, rigorously equal, form the other two arms of the bridge. When the machine is running either as a synchronous motor or as an alternator, the values of the resistances, R_1 and R_2, vary, the resistance R_2 increasing with respect to R_1. As soon as steady thermal conditions are attained the balance of the bridges is restored by means of a resistance box, r, and a wire of german silver, 1, provided with a slide which closes the circuit of the galvanometer.

The resistance, ρ, taken on the box, r, and the wire, 1, which restores the balance of the bridge, is proportional to the temperature difference desired. Designating by ρ_1 the correcting resistance for the calibrating test at the low pressure e_1, by ρ_2 that for the calibrating test at the higher pressure e_2, and by ρ the correcting resistance for the test under the considered load, there is obtained for the losses corresponding to this load:

$$p = (p_2 - p_1) \, \frac{\rho}{\rho, - \rho_1}$$

The application of this method requires, therefore, the measurement of two powers and three resistances.

Accuracy of method. It is possible to establish the values of the two resistances, R_3, and the resistance box, r, with a very high precision. The absolute values of the resistances, R_3, are of no importance. They need only be of the same order as the values of the resistances R_1 and R_2; but it is absolutely necessary that they should be rigorously equal to each other. Before being installed in the machine, the resistances, R_1 and R_2, are established with their definite connections and compared with each other. To this end, the elements being intermingled they are placed for a sufficient length of time in closed boxes to make sure that the temperature of all elements is the same. This is ascertained by the fact that when replacing, R_1 or R_2, or conversely, the balance of the bridge is not disturbed. The accuracy of the values of the ratio

$$\frac{\rho}{\rho_2 - \rho_1}$$ is thus very high so that the accuracy of the

method depends almost solely upon that of the watt-meters.

When making the calibration measurements it is advantageous, in order to increase the precision, to disconnect the alternator from the turbine; and this procedure should be followed every time the conditions of operation of the power plant permit it.

The possible error in the losses of one alternator, the efficiency of which is 96 per cent, or nearly so, varies from four to five per cent; with four per cent losses. The error in the efficiency therefore lies between:

$$4 \times 0.04 \text{ and } 4 \times 0.05 \text{ per cent}$$

say between   0.16 and 0.20 per cent.

Engineering and Economic Features
of Distribution Systems Supplying Increasing Load Densities

BY L. M. APPLEGATE[1] and W. BRENTON[1]
Associates, A. I. E. E.

Synopsis.—Large savings may usually be made in distribution systems by designing present meeds to fit in with future requirements determined from a study of population and utilization increase. A comparison of the total investment required and the annual operating costs of various systems to meet local conditions, points clearly to 4000-volt, four-wire primary distribution. The general procedure in studying the distribution system of the Portland Electric Power Company, utilizing standard methods and locally derived costs, is outlined.

* * * * *

THE average central station company has very carefully planned its generating and high-tension transmission systems with regard to economy and future growth. But in many cases the same careful thought has not been given to distribution, probably because the opportunity for saving is not so generally appreciated. The distribution system has no outstanding big physical features to attract interest; it is composed of a mass of small things, and unless the dollars to be saved are kept constantly in view, its importance may be overlooked. At the present time, however, a comprehensive study of the entire transmission and distribution system of the Portland Electric Power Company is under way. This paper is an outline of the method followed in the distribution study and is a presentation of the practical application of well-known economic theories to the case in hand. Before the study is completed this method will be applied to

every overhead feeder on the system. The requirements of each individual feeder section for a period of ten years are being determined and the entire system is being laid out to meet these needs. This layout involves the most economical conductor size, transformer size, and transformer spacing for the estimated load densities. As the system grows, every extension will be made in such a manner that it can be fully utilized in the ultimate plans.

The first step in the design of such a system is the
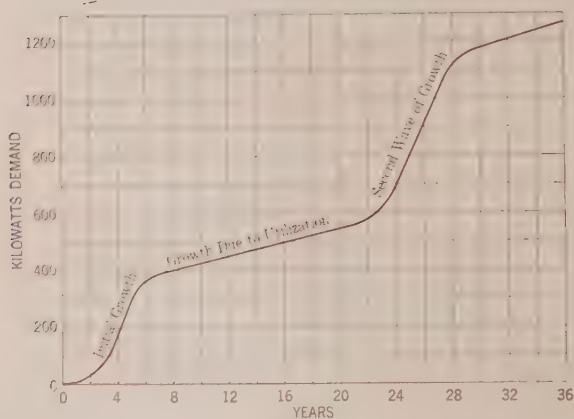
FIG. 1—TYPICAL GROWTH CYCLE OF A METROPOLITAN AREA

determination of the future loads to be expected and this involves a study of population and utilization increase in the affected areas. In order to illustrate the methods employed, a typical 2300-volt primary feeder section of the Portland Electric Power Company will be considered.

The increase in load in certain districts proceeds in cycles. The initial wave is usually the result of development as a residential district. After the first wave in growth has passed, the load may not show any marked increase for several years. There is, however, the gradual utilization increase, which, in residential sections, amounts to about ten per cent per annum. Fig. 1 illustrates such a growth. The second period of rapid load increase occurs as a result of rebuilding. The district under consideration is entering upon its second period of growth. It is an old residential district at the edge of a rapidly expanding business district.

The feeders in a district should be designed to serve several years after such a period of sudden growth. Various curves of population and load growth may be used for guidance in the forecasting of load, one of which is shown in Fig. 2. This particular curve represents the population served per block of business district of Portland. The ordinate values are the total population of Portland divided by the area in blocks of the central business district. The equation of the curve is

$$Y = \frac{3000}{1 + e^{4-0.05x}} + 300$$

y = Ordinate of Curve
x = Years since 1860

Dr. Raymond Pearl, in, "Studies in Human Biology," demonstrated that this form of equation represents the increase of density of population. The constants of the curve were derived from data obtained from the Oregon Historical Society. The curve indicates an almost constant rate of increase during the next twenty years, the increase in load being due to the population density increase and the increase in utilization. Since the rate of load increase due to each of these factors is expected to remain practically fixed during the next twenty years, the present rate of load increase is the one used for the forecast.

Fig. 3 shows the projected loads on this feeder and indicates that the capacity of the feeder should be increased before the winter of 1926-1927. This increase in load could be handled in several ways:

First. As a temporary expedient, part of the load could be cut over to adjacent feeders which are not quite so heavily loaded. This would delay the necessayr increase in capacity about one year, at which time all the feeders from this general district would be loaded to capacity.

Second. The present system of primary feeders could be extended, by running new feeders into the districts now served and dividing the load among the various feeders. This would require the installation of the substation feeder equipment consisting of the neces-
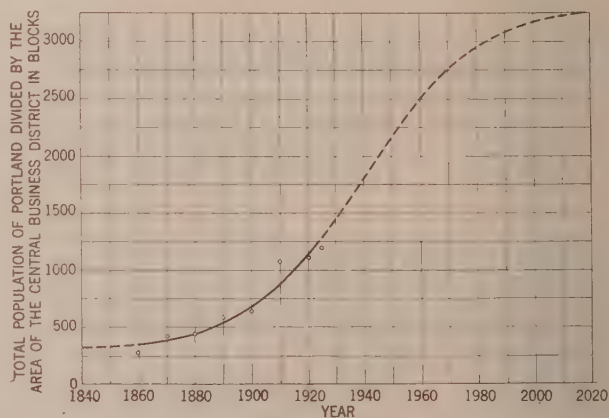
FIG. 2—RATE OF GROWTH OF PORTLAND

sary oil circuit breakers, and regulators. The polse would also be over-crowded by running the required number of new primary feeders to care for the next ten years growth.

Third. The capacity of each feeder could be increased for 2300-volt distribution, but this would require larger regulators, instrument transformers, etc., in the substation, and larger copper in the overhead lines.

Fourth. The anticipated growth could also be taken care of by an increase in voltage, such as the 4000-volt, four-wire system.

The table given below shows a comparison of the relative costs involved in providing service for the next ten years in the district covered. It does not, however, take the station or distribution transformers into account as they would be the same in each case.

Plan Employed	Total Investment Required by 1935, including Substation Equipment. Based on 100 for Present Investment	Annual Cost in 1935 (Fixed Charges on Total Investment, Annual Maintenance Cost, and Annual Energy Loss.) Based on 100 for present Annual Cost.
Using new 2300-volt Lines Paralleling Present Lines.................	159	165
Increasing Current Carrying Capacity.........	161	166
4000-volt Distribution.....	131	122

The advantage of 4000-volt primary distribution from the standpoint of investment required and annual cost is clearly shown.
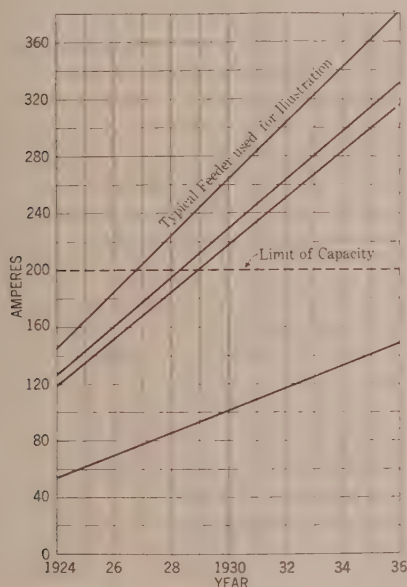
FIG. 3—PROJECTED LOADS ON GROUPS OF TYPICAL PRIMARY FEEDERS

The 4000-volt, four-wire distribution system is very well known, having been used in Chicago since 1898. It is also used in Baltimore, Boston, Toledo, Kansas City, Cincinnati, St. Louis, Louisville, Denver, Minneapolis, Pittsburg, Cleveland, and on the Pacific Coast in San Francisco, Oakland, and Seattle. However, it may not be out of place to mention some of the advantages gained by this scheme. The same conductors, insulators, pole top switches, regulators, oil circuit breakers, and station and distribution transformers now

used on the 2300-volt lines may be utilized. It is necessary to string the fourth wire, install the third regulator, and reconnect the station transformers Y on the secondary side and reconnect the distribution transformers from phase wire to neutral. In all cases under consideration the pole lines can accommodate the fourth wire, whereas there is not capacity for duplicating the 2300-volt feeders. The kv-a. capacity of the line for the same current flow is increased 73 per cent by using 4000 volts, and with this additional load, the voltage drop is reduced to 57 per cent of the drop
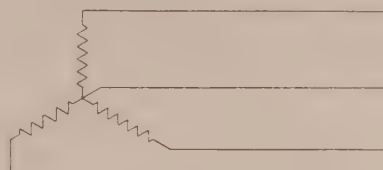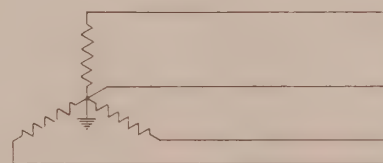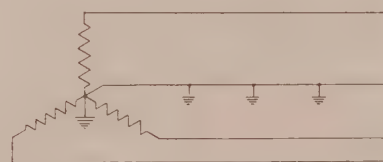
FIG. 4, 5 AND 6.—VARIOUS PRIMARY CONNECTION SCHEMES FOR 4000-VOLT DISTRIBUTION

with 2300 volts and the smaller load. Thus, both the carrying capacity and the regulation are improved at the same time. In the case of lines which have not yet reached their full current-carrying capacity, but are limited by the voltage drop, three times the present load could be carried on a 4000-volt line with the same percentage voltage drop, or with the same load, the voltage drop would be only one-third the drop at 2300 volts. Many different types of systems have been converted to 4000-volt, four-wire distribution, but no record has been found of a 4000-volt system being changed to any other type.

The only disadvantage claimed for 4000-volt distribution is the increased hazard to linemen. However, practically all companies in all geographic sections work their 4000-volt overhead lines hot, and experience seems to show that the percentage of accidents has not increased over that of the 2300-volt system.

There are four different connection schemes in use for 4000-volt distribution. Fig. 4 shows the neutral wire,

ungrounded. Fig. 5 shows the neutral grounded at the supply end only. No current flows in the ground except when a phase wire is grounded. In case of accidental ground on the neutral, from the point of accident to the station transformer the neutral wire and the ground are in parallel, and some ground current may flow. If there is an unbalanced load on the line under the latter conditions, unbalanced voltages will result. Fig. 6 shows the neutral wire grounded at many points along the line as well as at the station. Where the neutral parallels the ground, the wire must be of such size that the actual flow in the ground will be very slight; otherwise, inductive interference with telephone lines may result. Fig. 8 shows a common neutral for both pri-

FIGS. 7, 8 AND 9.—DISTRIBUTION TRANSFORMER CONNECTIONS

mary and secondary with ground connections at many points. The neutral must be heavy enough to carry the unbalanced current of both primary and secondary circuits, but there is usually a considerable saving in copper by using the common wire, and a pole position is saved in all cases. Using this method, the change to 4000-volt, four-wire distribution could be made even though the pole positions were all occupied. It will be necessary, in some cases, to increase the size of the neutral copper. The last method of connection is the one recommended for the adoption of this company.

It is proposed to cut over the feeders from the sub-stations having the heaviest load conditions first and then, as soon as possible, cut over all other overhead

feeders in the order of their needs. This applies to feeders with small loads as well, for the saving in losses and improvement in regulation makes such a change economical. It is also easier to make the cut-over before the load reaches its maximum.

At the time of the actual cut-over, a short interruption of service is necessary. In the present instance, the change-over will be very simple because there will be a 4000-volt bus as well as a 2300-volt bus in the station by the time the change is made and the feeders can be cut over one at a time. The necessary line transformer connections can probably be made in two or three hours some Sunday during the summer months between 4:00 a. m. and 7:00 a. m., at which time the demand is a minimum with respect to power, lighting, and cooking loads. It will also be light enough to work on overhead lines to good advantage.

One-third of the connections will be made before the time of the cut-over. The fourth wire, when in place, will be cut in parallel with one of the phase wires, say the A-phase. This will ground the A-phase until the time of the cut-over because the neutral wire will be grounded in many places. Then all of the transformers on the C-A-phase will be cut over to the fourth wire without interruption. At the time of the final cut-over, the jumper between the fourth wire and the A-phase will be removed and the fourth wire connected to the star points of the station transformer secondaries or the neutral bus in the station.

To accelerate the cut-over, all connections will be carefully traced out and checked. Tin tags of various shapes,—round, square, triangular, star, etc.—and approximately $2\frac{1}{2}$ in. in maximum dimension, will be stamped out. Each transformer lead to be reconnected will be tagged and a tag of the same shape will be placed on the line wire to which it is to be connected. This will make rapid night work possible if the necessity arises. Each pole where work is to be done will be listed by pole number and location, and definite sections assigned to various line foremen. At the same time the overhead cut-overs are made the station crew will connect the feeder over to the 4000-volt bus, or change the transformer secondary connections to Y, as the case may be; cut in the third regulator on each feeder, and make the necessary changes in meters, relays, etc.

The only load that will be affected by this change over to a higher voltage, will be the 2300-volt, three-phase motors. In these cases, 4000/2300-volt auto-transformers will be installed at the expense of the company. There are so few of these on the system that the expense is negligible.

All transformers will be connected to the phase wires through primary cut-outs, but will tie solidly to the neutral wire. These connections are shown in Fig. 7. In some cases, power and light will both be taken from the same transformers as shown in Fig. 9, which indicates two transformers in open delta. As indicated,

the reversal of connections of one of the transformers is on the primary side. This makes the installation of the third transformer possible at some future time without any changes in wiring.

The economic design of a distribution system to provide for future loads, involves the determination of the most economical voltage drop and wire size in both primary and secondary circuits, and the most economical transformer size and spacing. These, in turn, depend upon local costs and load conditions, and must be computed in each instance, although the general principles indicated here are applicable in all cases.

One of the items of expense involved is the cost of energy, and in some cases this may become a controlling factor. The method of finding energy cost for design purposes is distinct from the methods used for rate-making. Energy cost will differ for various parts of the system, for different times of the day, and for every load factor and power factor. Such an analysis may be carried to any degree of refinement. For the purpose in hand, it is considered sufficient to determine the energy cost at each substation involved. This cost is taken to be the sum of the demand, and the operating costs of the generating plants, the transmission system, and the substation under consideration. The demand cost constitutes the annual interest, depreciation and taxes, or the annual fixed charges pro-rated according to the yearly peak demand on the system. The operating charges are the annual operating and maintenance costs divided by the total kw. hr. generated during the year. Thus, for the generating stations, the total annual fixed charges divided by the maximum one hour peak for the year, gives the demand cost per kw. at the generating station bus. The same is determined for the transforming stations, the transmission lines and the particular substation under consideration. Taking into account that the demand cost per kw., on the generating station and transmission system will be increased proportionate to the various transmission and transformation losses, the demand cost of energy at the substation bus, will be the sum of the substation demand, plus the transmission demand, plus the generating station demand. The operating cost will be the sum of the operating costs of the three divisions mentioned. To reduce the demand cost at the substation to a kw.-hr. basis, the demand cost is multiplied by the substation demand at the time of system peak, and divided by the total kw.-hr. for the substation during the year. This figure added to the operating charge per kw.-hr. gives the total kw.-hr. cost of energy fed to the distribution system at the particular substation under consideration.

Another quantity involved in the determination of feeder losses is the "equivalent hours," or the number of hours required for the maximum peak load of the year to flow each day in order to give the same annual distribution loss resulting from daily and seasonal load fluctuations. The total line loss during the year is equal to $\Sigma\,(I^2\,R)$ loss for each hour of the year. If this quantity is divided by $I_{max}^2\,R$, the loss during the hour of maximum yearly peak, the result will be the number of hours for the year required for the maximum load to give the same annual loss. If the kw., or kw.-hr. readings are available instead of the ammeter readings, the same results are obtained by the expression

$$\frac{\Sigma\,[\text{ Kw.-hr. (per hour) }]^2}{[\text{Kw.-hr. (maximum hour) }]^2}.$$ It is evident that it

requires too much work to attempt such a computation. If, however, the computation is made for the maximum day for each month, the equivalent hours for each month based on the monthly peak will be obtained. This figure for each month may be reduced to the equivalent hours, based on yearly peak, by multiplying each by the square of the ratio of the peak for that month to the peak for the year. The average of the
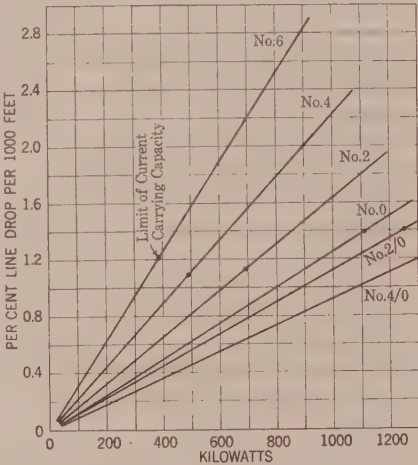
FIG. 10—PRIMARY FEEDER LINE DROP

equivalent hours for each month based on yearly peak will give the equivalent hours for the particular feeder being studied. By applying this figure for 330 days instead of 365, or using 0.9 of the above value for 365 days, compensation will be made for the Sunday and holiday loads. When a group of feeders from any particular substation feed similar districts, it is sufficiently accurate to assume that all will follow the same load fluctuations and the equivalent hours as determined from the feeder bus may be applied to each feeder connected to the bus.

Most of the formulas used in the distribution design have been taken from Reyneau and Seelye, "Economics of Electrical Distribution." It is not the intention to repeat a sufficient number of these for a working knowledge of the subject or to give the details of their derivation. A few are given merely to illustrate the general type.

Figs. 10 and 11 illustrate some of the curves which have been prepared for the study of primary circuits. The

study of secondary circuits begins with the determination of transformer costs. Fig. 12 shows the annual charges on transformers, which must be derived from local costs. The iron losses are dependent on the cost of energy as derived for the particular feeder considered, and the copper losses are affected not only by the energy costs, but also by the equivalent hours for the feeder. The fixed charges depend upon local first costs, installation costs and rates of interest, taxes, and depreciation.
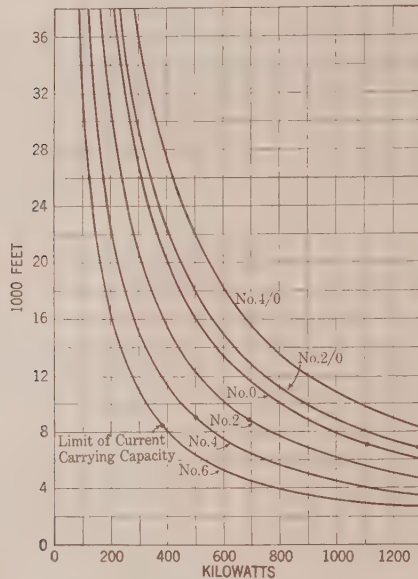
FIG. 11—PRIMARY FEEDER TRANSMISSION DISTANCES

The following formula gives the expression for the total annual cost of secondaries and transformers per 1000 feet of line.

$$Y = \frac{1000}{S} \left(K_1 + \frac{K_2 L_D S}{1000} \right)$$

$$+ \frac{G_L}{100} \left(3000 \, W \, C_{cu} + C_{sr} \right)$$

$$+ S^2 \left(60.83 \, \frac{L_D{}^2 \, \rho t \, C_{e2}}{A \, E^2 \cos^2 \theta} \right)$$

By equating the first derivative of Y with respect to S = zero, the most economical transformer spacing is found to be

$$S_e c = 2.02 \left(\frac{K_1 \, E^2 \cos^2 \theta}{\rho t \, C_{e2}} \right)^{\frac{1}{3}} \frac{A^{\frac{1}{3}}}{L_D{}^{\frac{1}{3}}}$$

From this, the most economical transformer size is

$$T_e c = L_D \frac{S_e c}{1000}$$

The most economical conductor size for secondaries is

$$A_e c = \frac{154}{(G_L \, K_4 \, C_{cu})^{\frac{1}{4}}} \left(\frac{K_1{}^2 \, \rho t \, C_{e2}}{E^2 \cos^2 \theta} \right)^{\frac{1}{4}} L_D{}^{\frac{1}{2}}$$

Symbols—

Y = Total annual charges on secondaries and trans. per 1000 ft.

S = Spacing of transformers in feet.

K_1 & K_2 = Constants derived from upper Curve Fig. 12.

L_D = Load density in kw. per 1000 ft. of line.

G_L = Per cent interest, taxes, and depreciation on lines.

W = Weight of insulated wire in pounds per ft.

C_{cu} = Cost of insulated wire per pound.

C_{sr} = Cost of stringing 1000 ft. of line.

ρ = Resistivity of copper per mil-ft.

t = Equivalent hours.

C_{e2} = Cost of energy loss per kw-hr.

A = Area of wire in cm.

E = Voltage between outside wires.

$\cos \theta$ = Power factor of load.

T = Transformer size.

A large number of curves have been plotted from the various formulas using locally derived constants.
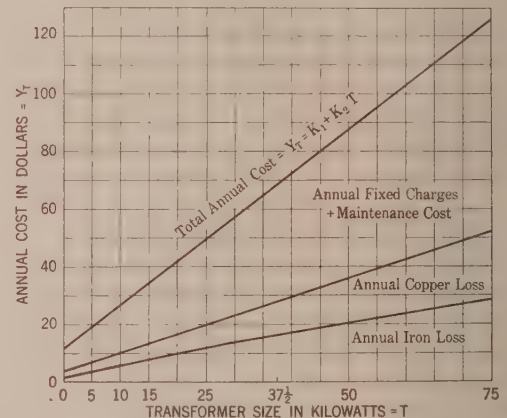
FIG. 12—ANNUAL CHARGES ON DISTRIBUTION TRANSFORMERS

These curves are used in the various layouts and greatly facilitate the work. They are to be kept up to date as cost conditions vary, so that there will always be at hand curves of ready reference to be consulted when extensions on short notice are required.

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Some Features and Improvements on the High-Voltage Wattmeter

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Associate, A. I. E. E.

THE high-voltage wattmeter herein described is the result of three years of study and experimental work carried on at Stanford University. Included in this report on the wattmeter is a description of a high-voltage voltmeter and a crest voltmeter. The operation of these instruments is entirely independent of any connection to the supply transformers. In other words the equipment in its present form can be connected directly in on the high voltage line and simultaneous readings of the power, total effective

(See diagram of connections.) These instruments are all read with telescopes at a safe distance. This special multiplier consists of a column of ordinary tap water 16.5 ft. long and 3/16 of an in. in diameter; it has a maximum resistance of approximately three million ohms and a current carrying capacity of 65 milliamperes. A rubber air hose is used as container for this column of water. This hose is wound into a helix of five turns about one foot in diameter and the helix is placed with its axis vertical between two horizontal circular plates
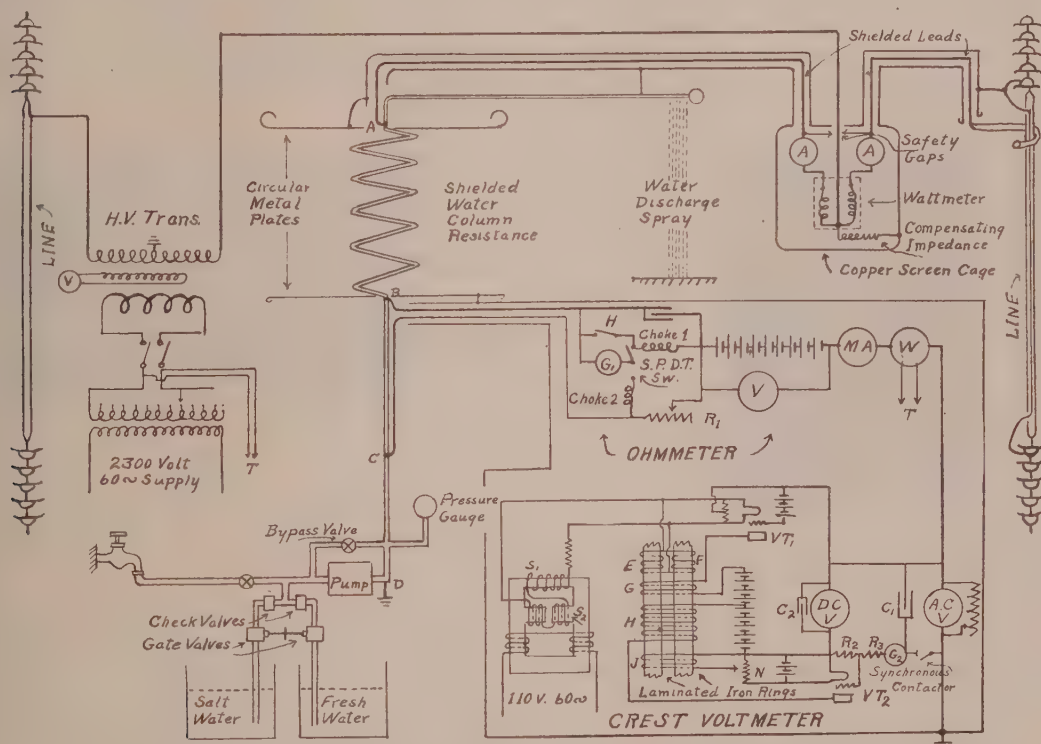
FIG. 1—WATTMETER CIRCUIT ASSEMBLY

voltage, crest factor and line current can be taken at any instant and at any voltage up to 175 kv. to neutral.

The wattmeter consists of an ordinary low-voltage instrument located in an electrostatically shielded cage that is at high potential. The current coil of the meter is connected directly in on the line with an ammeter in series. The potential coil with its special high resistance multiplier is connected from the line to ground. There is also a milliammeter in this circuit.

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four feet in diameter and separated thirty inches. These plates are supported by three bakelite strips 1 in. by 3 ft. 1 in. long. The hose is held in place by means of a single bakelite strip with wooden pegs of 3/8 in. maple doweling projecting out radially, on the end of which the hose is fastened. (See Fig. 2.) The water is forced up the hose by means of a gear pump; the maximum pressure used being about 80 lbs. per sq. in. and the maximum flow being about 1.5 gal. per min. After reaching the top of the helix and passing the wattmeter connection, the water flows through about seven feet more hose and is then discharged to the ground in a spray—the spray completely breaking the circuit.

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When the current flows through the water resistance the water, of course, warms up, the heating being accumulative as the water moves up the hose. The effect of this is a somewhat complex change in resistance which in turn makes the voltage gradient down the column differ from a straight line function. This is a condition that must be controlled before correct electrostatic shielding can be accomplished. First of all a means must be had for keeping the voltage gradient down the column constant at all voltages. The next problem is then to match the potential of the water column at every point by the external field between the two plates.

Before going further, let us solve the problem of a current flowing through this column of water that is being constantly supplied at the lower end with cool water and wasting the warm water at the top. The resistance-temperature coefficient of ordinary tap water varies considerably for different temperatures. The

Fig. 2—The Shielded Water-Column Resistance used as the Wattmeter Multiplier

following has been found to be approximately the relation of resistance to temperature between zero and 100 deg. cent.[2]:

$$R_t = \frac{40 \, R_{20}}{20 + t}$$

Where R_t is the resistance at any temperature t (deg. cent.) between 0 deg. and 100 deg. and R_{20} is the resistance at 20 deg. cent.

Beginning at the ground end, the rise in temperature $d\,t$ in a differential length $d\,l$ of the column is as follows:

$$d\,t = \frac{I^2 \, d\,r \, \dfrac{d\,l}{V}}{4.184 \, A \, d\,l} = \frac{I^2 \, d\,r}{4.184 \, A \, V} \tag{1}$$

Where I = current in amperes through the w. c.

            $d\,r$ = resistance of a length $d\,l$.

2. From tests by Applequest and McKenny, M. I. T., 1912. *Pender Handbook*, (edt. 1922,) p. 1356.

V = velocity of water through the column in cm. per sec.

A = area of column in sq. cms.

4.184 = mechanical equivalent of heat.

Integrating the above equation the actual temperature of this differential length is,

$$t = \frac{I^2 \, r}{4.184 \, A \, V} + T \tag{2}$$

T being the temperature of the water entering the column.

$$d\,r = R_t \frac{d\,l}{A} \tag{3}$$

R_t specific resistance of the water at temperature t.

$$R_t = \frac{40 \, R_{20}}{20 + t} \tag{4}$$

R_{20} specific resistance at 20 deg. cent.

Substituting (4) in (3),

$$d\,r = \frac{40 \, R_{20} \, d\,l}{(20 + t) \, A} \tag{5}$$

Substituting (2) in (5),

$$d\,r = \frac{40 \, R_{20} \, d\,l}{\left(20 + \dfrac{I^2 \, R}{4.184 \, A \, V} + A \right) A} \tag{6}$$

Simplifying,

$$(83.68 \, A \, V + 4.184 \, A \, V \, T + I^2 \, r) \, d\,r = 167.4 \, V \, R_{20} \, d\,l \tag{7}$$

Integrating,

$$\left(\frac{I^2 \, A}{2} \right) r^2 + A \, V \, (83.7 + 4.184 \, T) \, r - 167.4 \, V \, R_{20} \, l = 0 \tag{8}$$

Solving for r,

$$r = \frac{- A \, V \, (83.7 + 4.184 \, T) \pm \sqrt{A^2 \, V^2 \, (83.7 + 4.184 \, T)^2 + 335 \, V \, R_{20} \, I^2 \, l}}{I^2} \tag{9}$$

This gives the resistance for any length equation (1) when the following are known: the area of the column, velocity of the water, specific resistance of the water at 20 deg. cent., the initial temperature of the water and the current through the column.

Equation (9) shows something that was practically self-evident, that is, as the current I changes it is possible to keep the resistance all along the column constant by changing V, the velocity of the water. As can readily be seen the velocity must vary as the square of the current—as would be expected.

If the maximum effective value of the current to be used is fixed and the allowable temperature rise (if a glass tube were used instead of rubber this temperature could be 100 deg. cent.) of the water decided upon, then the distribution of voltage down the column can be computed. When this is done the pitch

of the helix can be changed in such a manner that the potential of the water column at all points is the same as the space it occupies between the two plates—under these conditions the shielding is ideal. In order for the voltage gradient of the column to remain constant it is only necessary to keep the temperature of the ingoing and outgoing water constant. The temperature of the ingoing water is easily adjusted. The temperature of the outgoing water is controlled by regulating the velocity. To tell when the temperature was correct a thermometer could be placed in contact with the water at the discharge end and read by means of a telescope. However, a more direct method than this was employed. A wattmeter was connected in the ground circuit of the water column as shown in the diagram of connections. One coil carries the current that passes through the water resistance and the other coil of this wattmeter with suitable resistance is connected across the low voltage primary of the high voltage transformer. The wattmeter reading will be
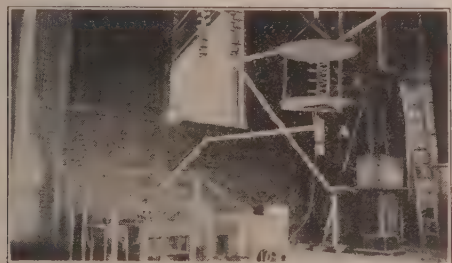
Fig. 3—View of High-Voltage Wattmeter and Auxiliary Equipment

At center on right is insulated screen cage enclosing wattmeter instrument and milliammeters; at the top on right is shielded water column resistance; in center at bottom is hydraulic apparatus, and at left is cage containing crest voltmeter and ohmmeter

an indication of the amount of power absorbed by the water column. So that, for example, if the conductivity of the supply water remains constant and the line voltage is doubled, the reading of this wattmeter will be increased four times which means that to keep the temperature constant there must be four times the quantity of water flowing through the hose. This, of course, will require a certain increase in water pressure. By knowing the constants of this wattmeter and the water flow in terms of the pressure-gage reading, a scale was made for the wattmeter so that instead of reading watts the wattmeter indicates the pressure necessary to keep the temperature of the outgoing water constant. This works out very well under actual test; with the conductivity of the supply water constant the resistance of the water column was determined at various voltages and found to be practically constant. This, of course, means that the voltage gradient down the column remains constant. Assuming that the temperature resistance equation is not altered by the introduction of salt into the water, the value of R_{20}

can be changed, thereby uniformly increasing r throughout the length of the column. This will, of course, increase I; hence V must be correspondingly increased. This will not change the voltage distribution down the column and therefore will not alter the shielding. In other words, the resistance of this resistor can be uniformly changed throughout its length without changing its dimensions.

The necessity of the exact matching of the field established by the water column with that between the two plates has been found by integrity tests. On account of the relatively large charging current through the line coil of the wattmeter, it requires only an extremely small capacitance current through the other coil to produce a fair sized deflection, which of course is error-reading. Any field picked up or supplied by the water column will cause such an error. To test for correct shielding, a reading of the line wattmeter is taken at a certain water conductivity and line voltage; then with the line voltage kept constant, water of, say, twice the conductivity is used which should double the original wattmeter reading if the shielding is correct. The only thing that is changed during this test is the conductivity, the physical dimensions of the circuit and the voltage gradient down the column remain unaffected. If the wattmeter reading is not proportional to the current in the potential circuit at constant line voltage, there is error-reading due to improper shielding. However, as discussed in a previous paper on the high voltage wattmeter,[3] an error-reading can also be the result of improper shielding of other parts of the circuit besides the water column. After the present water column was designed and built the above test was applied and the shielding was found to be correct within the limits of observations. Besides the above test another obvious advantage of being able to change the resistance of this wattmeter multiplier is to greatly increase the wattmeter readings at the lower voltages.

The change in the resistance of the water column is accomplished by the introduction of common salt into the water. The water supplying the pump is drawn from two tanks one fresh and the other a salt solution. The valves on each line from these tanks are connected together in such a manner that as one opens the other closes. When the valves are once set the mixtures remain constant to a surprising degree of steadiness. The gear pump no doubt aids considerably in the mixing process; also, the bypass valve is never completely closed when the salt solution is being used. The hydraulic system of controls must be such that the pressure and hence, the flow can be changed without affecting to any great extent the conductivity. One thing necessary in order to do this is to maintain the level of the water in the two supply tanks constant and

3. "Power Measurements at High Voltages and Low Power Factors," by Joseph S. Carroll, Thomas F. Peterson and George R. Stray. Journal A. I. E. E., p. 941, Oct. 1924.

equal at all times. Also the change in conductivity should not alter the flow, however, as the conductivity is changed the flow must be controlled to keep the temperature constant.

The Ohmmeter

The resistance of this wattmeter multiplier is determined in the following manner (See diagram of connections) while the high voltage is on: A storage "B" battery of about 100 volts is inserted in the ground end of the water column. This battery forces a direct current through the galvanometer G_1, the choke 1, up through the water column, through the secondary winding of the high voltage transformer, to ground and back to the other side of the battery. This direct current goes only through the galvanometer whereas the alternating current is allowed to pass only through the 10 m. f. condenser in parallel with the galvanometer and choke. Knowing the voltage of the battery and the calibration of the galvanometer the resistance of the water column can be determined. Of course, the resistance of the transformer winding and choke must be subtracted and the drop across the condenser be corrected for if necessary. Knowing the resistance of the water column and the effective value of current through it, the total effective line voltage can be computed. The values of voltage obtained in this manner check on an average within .5 per cent of the voltage as measured by the voltmeter coil within the transformer. This difference at present is about the limit of our accuracy.

To obviate the necessity of insulating the apparatus at the ground end of the water column in order that the current through the galvanometer shall have only one path to ground, a connection is made from the battery through a resistance R_1 and to a point C on the lower end of the water column. The current in this circuit flows from C to the ground at D. The resistance of R_1 is made such a value that the drop across it is the same as the drop across the galvanometer and choke. This puts the point B at the same d-c. potential as C so that there is no current flowing between B and C and the only current through the galvanometer is that through the water column. To test for the equality of potential of B and C, a single-pole double-throw switch is connected in the circuit so that the galvanometer can be connected between these two points with a choke 2 in series. The resistance R_1 is then adjusted until there is no current through the galvanometer and then the switch is thrown back to connect the galvanometer in its normal position. The switch H is, of course, closed during this operation of balancing. This balance when once made remains the same throughout the test, the ratio of the resistance between C and D, and A and B is the same for all conductivities. The resistance of the water between B and C is never less than 50,000 ohms and for the higher voltages it is 500,000 ohms. The resistance from C to D is about half that between

B and C and is sufficient to limit the current drawn from the battery to a reasonably small value. Since the resistance of the galvanometer G_1 is only 14 ohms and that of the choke 1 is about 7500 ohms, no correction is necessary when the galvanometer is shifted from one place to the other. The a-c. drop across the condenser is 16 volts with a current of .060 amperes at 60 cycles, however the secondary of an audio transformer keeps the galvanometer free from vibration due to this voltage.

The Crest Voltmeter

The crest values of voltage are determined by multiplying the effective values by the crest factor. This crest factor is determined as follows: The current through the water column has the same wave-form as the line voltage so that an ordinary voltmeter inserted in the ground end of the water column will give a replica of the total line voltage. By means of a synchronous driven contactor, a condenser is charged with the crest value of this effective voltage, the ratio of these two being the crest factor. The voltage of this condenser could be determined directly by means of an electrostatic voltmeter, however the time of taking readings does not permit the use of such slow acting instruments. In place of such a voltmeter, a practically instantaneous self-balancing potentiometer was used in which the voltage of the condenser is read by means of the ordinary quick acting d-c. voltmeter. Before the operation of this potentiometer is taken up, a brief description of the different parts will be given.

The current through the d-c. voltmeter is furnished by a storage "B" battery of about 135 volts. This current also passes through the plate circuit of a 201A vacuum tube, $V T_1$ (See diagram) and through the winding G on an iron core choke. The filament current of $V T_1$ is a-c. and is furnished by a specially designed constant current transformer. In parallel with this filament are the windings E and F of a choke made up of laminated iron rings; the winding E is around half of the rings and F is around the other half. The windings G, H and J are around all of the rings. The coils E and F are connected in parallel in such a manner that the flux set up by the current through them is in opposite directions and hence there is no voltage induced in the other windings. There is a positive bias put on the grid of $V T_1$ to reduce its filament to plate resistance. $V T_2$ is also a 201A tube and might be called the detector tube since it detects any difference between the potential of the condenser C_1 and the voltage at the terminals of the d-c. voltmeter. The filament of this tube is lighted with a four-volt storage battery. Sixty-five volts of the storage "B" battery are used on the plate of this tube; in this plate, circuit is the coil H consisting of 10,000 turns of No. 36 B. & S. d. s. c. copper wire. There are 250 turns in coil J which are used to produce a field almost equal and opposite to that of H.

With this description of the apparatus, the operation will now be taken through step by step. The alternating current through the water column resistance on its way to ground passes through the a-c. voltmeter and its non-inductive shunt—the shunt being necessary on account of the current carrying capacity of the voltmeter. The effective value of the voltage across the voltmeter is kept about 50 volts on the 75-volt scale by means of the shunt resistance; however, this is only for the convenience of reading and the operation over a range from 35 to 70 volts gives accurate results. The crest of this voltage is picked off by the synchronous contactor and charges the condenser C_1. If to begin with this potential is not the same as that across the d-c. voltmeter there will be a current through the galvanometer G_2, in this case the current through the bias winding J is changed by means of the potentiometer N until there is no current through G_2. This is the only adjustment necessary and when once set it requires but very little changing. With the deflection of G_2 zero the d-c. voltmeter gives the potential of the condenser C_1. This reading divided by the reading of the a-c. voltmeter, is of course, the crest factor. Now, suppose that the a-c. voltage decreases; this will lessen proportionately the potential of C_1 and the d-c. voltmeter will momentarily be the same as before, a current then will flow through G_2, R_2 and R_2 for a very short time making the grid of $V T_2$ positive with respect to the filament. This will increase the plate current which is also the current through the coil H; this increases the saturation of the iron core and reduces the reactance of the windings E and F. Since these windings carry about 80 per cent of the constant current from the filament transformer, the filament current of $V T_1$ will be reduced. This increases the filament to plate resistance which will in turn diminish the current through the d-c. voltmeter and bring down the voltage across it until it is the same as the potential of C_1. In case the a-c. voltage rises, just the reverse of these operations will take place. The coil G in series with the d-c. voltmeter might be called a tickler winding, the number and direction of turns are such that the change in the current through the voltmeter produces just sufficient change in the saturation of the iron so as to keep the voltmeter where it is put without maintaining extra current through the coil H by a difference of potential between C_1 and the d-c. voltmeter. A very good test of this is to disconnect C_1 from the contactor while it is charged, the needle of the d-c. voltmeter stands practically still. If part of the charge is allowed to leak off the condenser, the voltmeter will immediately drop to that potential and remain there when the leak is taken off—thus demonstrating the minute amount of current necessary through R_2 to operate the system. One thing that aids considerably in the sensitiveness of this apparatus is the fact that the vacuum tube $V T_1$ is operated where the plate current is most sensitive to a change in filament current; for example, a change in filament current from 200 milliampere to 215 milliampere will change the plate current from about 3 milliamperes to 6 milliamperes with the 16,000 ohms of the voltmeter in series.

The condenser C_2 of 1 μ. f. is necessary in order to smooth out a small component of a-c. on account of using 60 cycle current to light the filament of $V T_1$. These ripples produced an a-c. potential between the grid and filament of $V T_2$ which was rectified leaving the grid negative and thus causing trouble. The resistance R_3 was found necessary to damp out very low frequency oscillations or hunting between the two condensers C_1 and C_2, caused mainly on account of the time lag in the change in temperature of the filament of $V T_1$.

The transformer furnishing the current for $V T_1$ was designed to take care of any reasonable fluctuation in line voltage. Since $V T_1$ is sensitive to slight changes in filament current, any change in line voltage would have to be adjusted for by $V T_2$ which is not the primary duty of this tube. This transformer furnishes practically a constant current in the secondary circuit with a 10 per cent change of primary voltage. One part of the secondary S_1 is wound on a practically saturated iron core. In series with this winding and 180 deg. opposite in phase is a winding around an air-gap magnetically in parallel with the saturated core of the other winding. The winding S_2 gives about half the voltage of S_1. With a change in primary voltage the flux across the air-gap changes at about twice the rate as that through the iron core; in this way the two changes just offset each other. The adjustment of the two secondary windings is made in an over all manner by means of a milliammeter in the plate circuit of $V T_1$. Of course the secondary current of this transformer is far from a sine wave but this is in no way a handicap.

The crest voltmeter circuit may seem elaborate, however, it has been found worth while in order to have an electrostatic instrument with the advantages of the modern highly damped sensitive d-c. voltmeter. The operation of this crest voltmeter is simple and reliable and to further improve its simplicity, it is hoped that sometime the synchronous contactor can be replaced by a special vacuum tube.

Another feature that has been added to the equipment is a 230-ft. line of hollow copper conductor. With this conductor it is possible to electrically cut out both strings of insulators as shown in the diagram and hence measure only the losses from the conductor. By changing the connections, the insulator losses may be included with the loss from the conductor or else they may be measured separately. The insulators are cut out by supplying the power to them directly and not through the wattmeter. The power is supplied to the string at the far end by running an insulated wire through the hollow conductor and connecting it back of the first insulator.

The work this year has been largely development

work, however, several tests were made on the three 230 ft. lines in the rain and also in dry weather. The results of the tests substantiate very well the work done with the wattmeter last year. During the rain tests, the fact was again emphasized that a rain test does not mean much unless the rate of rainfall is determined because the power loss varies considerably with the rate of rainfall. Next year it is planned to have a rainfall indicator and to find the relation between the rate of rainfall and the power loss from the different conductors and insulators.

Encouraged by the success of the present wattmeter, the design of the million-volt wattmeter has been begun. The crest voltmeter and ohmmeter in their present form can be used with but very little change. The main problem will be the fifteen-million-ohm, shielded multiplier.

Stored Mechanical Energy in Transmission Systems

BY J. P. JOLLYMAN[1]

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Synopsis.—The paper considers the performance of the stored mechanical energy in the moving masses connected synchronously to a transmission system during changes in load, changes in input and changes of transmission capacity,

The stored mechanical energy greatly affects the performance of a transmission system during sudden changes in transmission line capacity occasioned by switching out or in a parallel circuit. Such switching operations lead to oscillations of input due to the interaction of stored mechanical energy and the altered difference in phase between generated and received voltages over a transmission line.

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THIS paper will consider the performance of stored mechanical energy in a transmission system during changes in load, in input and in transmission capacity.

TYPICAL TRANSMISSION SYSTEM

For this paper's purpose, a typical transmission system will be considered to consist of two or more generating plants connected to a network feeding load centers by double circuit lines of considerable length. Some generating capacity may exist near the load centers, but its existence or absence has little effect on the subject under consideration.

Mechanical energy is stored in every moving mass connected to a transmission system. The most important of these masses are those revolving elements, the speed of which fluctuates with changes in system frequency. The rotors of synchronous machines, such as generators, synchronous motors, rotary converters and synchronous condensers, are of greater importance than the rotors of induction motors or the revolving parts of machinery driven by induction motors because the synchronous machines must follow the system frequency precisely while induction motors have some slip. The stored energy in devices such as street cars connected to a transmission system in a non-regenerative manner, does not influence the performance of the stored energy of the system.

TYPICAL FLYWHEEL EFFECTS

The greatest flywheel effects per kv-a. of capacity will usually be found in the rotors of large generators. Typical flywheel effects are:

Large hydro unit — 27,000 kv-a., 225 rev. per min. $W R^2 = 5,000,000$.

Stored energy = 43,031,250 ft-lb. = 16.2 kw-hr. = 1590 ft-lb. per kv-a.

Small high speed hydro unit — 7500 kv-a., 514 rev. per min. $W R^2 = 200,000$.

Stored energy = 8,976,000 ft-lb. = 3.37 kw-hr. = 1195 ft-lb. per kv-a.

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Synchronous condenser — 20,000 kv-a., 600 rev. per min. $W R^2 = 500,000$.

Stored energy = 30,600,000 ft-lb. = 11.5 kw-hr. = 1530 ft-lb. per kv-a.

Total Flywheel Effect of System

The total flywheel effect of a large transmission system is difficult to estimate but may be of the order of 2000 ft-lb. per kv-a. of connected generator capacity. Assuming 1.25 kv-a. of generating capacity for each 1.00 kw. of load a five per cent increase in load will reduce the speed from 60 to 59 cycles in about two seconds, if the mechanical input is held constant.

Many classes of load decrease with a decrease of speed. Among these are centrifugal pumps, and other motor-driven devices. Experience on a typical large transmission having a load of 300,000 kw. indicates a loss of about 3.5 per cent in load for a reduction in speed from 60 to 59 cycles and a corresponding gain for an increase of one cycle.

Performance of Stored Mechanical Energy During Load Changes

An addition of load to a transmission system does not cause an immediate increase in input of the governing generators. The governors are responsive to speed only; hence cannot add input until the speed has dropped the 0.1 per cent to 0.2 per cent necessary to cause the governors to act. The additional load is supplied from the stored energy of the system while the speed is decreasing to a point where the governors start to act. The input is then increased until the speed returns to normal or until it returns to the speed corresponding to the load on the governing units, depending on whether the governor is adjusted to maintain a flat speed or a drooping speed.

Where two or more generating units are governing at the same time, their governors must be set with a drooping speed characteristic. In such cases the speed will not return to normal unless the synchronizing motors of the governors are readjusted.

A reduction in load causes a similar train of events. The governing unit does not immediately decrease its input. The excess input increases the stored energy with the increase of speed necessary to bring the governor into action, whereupon the speed returns to normal.

A consideration of the events attendant upon a change of load shows the fallacy of a speed governor which is controlled by the electrical output of the governing unit. The only change in output occasioned by a change in load is the share of the total stored energy contributed by the governing unit. If the governing unit is to maintain speed it must be controlled by speed.

Performance of Stored Mechanical Energy During Changes in Input

A generating unit may be separated from the system by the operation of a switch with the result of a sudden decrease of the input to the system.

The general effects are the same as when a load is suddenly applied. The stored energy of the system is drawn upon until the speed drops to a point where the governors begin to act.

A sudden decrease of input due to switching off a generator under load causes an oscillation of the stored energy of other generating units in the same or nearby plants with respect to the system at the receiving end of a transmission line. The flow of power over a transmission line is accompanied by a lag in time phase of the receiver voltage behind the impressed voltage. The difference in phase depends upon the length of the line and the amount of load carried. This difference in phase is analogous to the twist in an elastic shaft occasioned by a torque. The degree of twist between the ends of the shaft depend upon its length and the torque applied.

The sudden tripping of a generator under load leaves the remaining generators in the same plant in an angular position ahead of the angular position corresponding to the decreased input to the transmission line. These generators must drop back in angular position, hence,
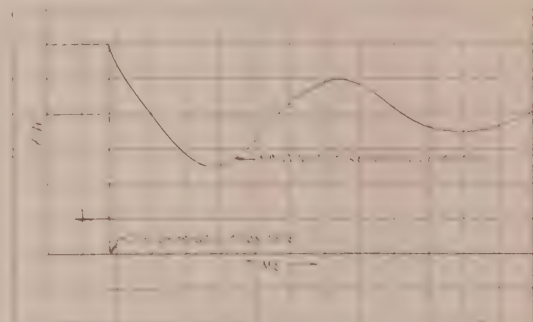
Fig. 1 —Oscillation of Output due to Sudden Loss of Generator

must slow down slightly and yield some of their stored mechanical energy. Finally, the generators must return to the system speed and the normal amount of stored energy. The process involves an oscillation of the angular position of the generators with respect to the synchronous equipment at the receiver end of the line with a corresponding oscillation of electrical output. This oscillation is independent of the mechanical output of the prime mover which will usually remain constant, since the changes in speed during the oscillation will usually be less than those required to cause the governors to act. Fig. 1 shows the character of this oscillation.

An increase in input as might be occasioned by a plant pulling up a block of load acts in a manner similar to a decrease of load,—the stored energy is increased with the increase of speed to the point where the governors begin to act.

Since increases of input are usually less sudden than decreases due to the separation of a generating unit, the

attendant oscillations are usually less pronounced. Such as occur are due to the increase in the phase angle over the line which must take place before the line can deliver additional load.

The Performance of Stored Energy During Changes in Transmission Line Capacity

Stored energy is an important factor in the performance of a transmission system during changes of transmission line capacity occasioned by switching out or in a parallel circuit. Such an operation results in a sudden change in the load on the line or lines remaining in service. The change of load on the line requires a change in the angular position of the generator voltage with respect to the receiver voltage. This

FIG. 2—OSCILLATIONS OF SPEED, STORED ENERGY, GENERATOR OUTPUT AND ANGLE BETWEEN GENERATOR AND RECEIVER VOLTAGE DUE TO ONE OF TWO PARALLEL TRANSMISSION LINES TRIPPING

change in angular position requires a change in stored energy and the transition is accompanied by an oscillation.

The case most likely to cause difficulty is the loss of one of two parallel circuits when the load on the remaining circuit approaches the limit of synchronous stability. Under these conditions the oscillation in kilowatt input arising from the oscillation of the stored energy may result in an input which exceeds the stability limit even though the steady state input is considerably under the limiting load for the remaining line.

A better understanding of the subject may be had by considering the performance of the generators at the time one of two circuits is switched out. Reference is made to Fig. 2.

Preceding the instant the parallel line trips out, the angle between the generator and receiver voltage may be $n°$. When the circuit trips, the remaining circuit cannot carry the total load until its angle has become even more than $2 n°$, hence the generator output drops to about half of its previous value and the excess of input from the prime mover increases the stored energy and the speed until the normal generator output is restored.

At this point the generator is running faster than the receiver, hence the output continues to increase until the excess stored energy is reduced to normal when the generator will be slowing down. Thus an oscillation of kilowatt output, angular difference between generator and receiver voltages and stored energy is started which may result in a maximum kilowatt input exceeding the limiting load the circuit can carry.

The performance of the transmission system under these conditions is greatly complicated by the fact that the sudden decrease in input attendant upon a line opening, starts an oscillation of the synchronous receiving apparatus with respect to the generators.

The period of oscillation of each synchronous unit will depend upon its $W R^2$ per kv-a. which will usually be different for each unit of different size or character. The resultant performance of the transmission system is extremely complicated and probably impossible to predict with accuracy. Observations indicate that the oscillations of energy flow in the transmission system are composed of several different frequencies superimposed.

Switching in a second parallel circuit also causes an oscillation of mechanical energy with the reverse effects to those observed for switching a line out. The generator output will be momentarily increased, followed by an oscillation. Such an operation is probably less likely to cause synchronous instability than switching out a parallel circuit, however a severe disturbance may be set up. A much better method of operation consists in transferring generators to the incoming line and equalizing the loads before the lines are paralleled at the generating plant.

ITALIAN ELECTRIC POWER INDUSTRY

A rapid increase in the capacity of power installation in Italy has been going on since the war; at the end of 1924 the total installed capacity was nearly double that of 1918. A corresponding increase has taken place in consumption, and while the yearly load factor in 1924 was slightly below that of 1918, it was considerably higher than in 1908, and shows an improvement as compared with 1920 and 1922. As steam plants represent about 20 per cent of the total capacity, and operate on the average for only about 600 hours per year, the load factor for the hydroelectric plants reaches approximately 40 per cent.

Transmission Stability
Analytical Discussion of Some Factors Entering into the Problem

BY C. L. FORTESCUE[1]
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Synopsis.—*The subject of stability has been much discussed lately, because it has an important bearing on future large power developments. In the early stages of a large program, such as the proposed superpower program, good engineering and common-sense dictate that each step should be very carefully considered from all points of view, since a blunder or failure to give proper weight to some important factor, such as stability, might set back the development program for many years.*

A brief historical review of the subject of stability follows; for those who are not familiar with "static" stability there is a review of the subject in the Appendix.

A criterion of stability is suggested based on present operating conditions, namely, that for reliability each unit of the superpower shall be at least equal to the best that has heretofore been obtained with similar power systems.

The necessity of a careful study of the characteristics of all machinery connected to the transmission line is pointed out. The necessity of proper inherent characteristics in generators and synchronous condensers is emphasized, and particular stress is laid on the necessity of proper volt ampere characteristics both inherent and with the exciter.

The action inside a generator during the transient following a change in load is discussed; it is pointed out that the true field is a resultant due to several magnetomotive forces in addition to that of the field circuit; the combined effect is a marked tendency to self-excitation, and inherent self-excitation would take place if it were not for the damping effect of resistance in the different circuits.

A brief review of other factors entering into the problem is given. These factors comprise inertia of moving parts, mechanical torque, speed of relays, circuit breakers, etc. The difficulty of correlating all these quantities is pointed out, and a basis on which it is practical to make computation is suggested.

Those who have not studied the subject of stability are recommended to read the Appendix before proceeding with the subject of transient stability.

The subject of transient stability is opened with a definition of stability of a power system.

The elements of the problem are discussed in some detail. The problem is one of obtaining the conditions of equilibrium, taking into account mechanical or applied torque, electrical or counter torque, inertia torque and damping factors, in addition to the electrical characteristics of the system. The action of a generator under suddenly applied load is discussed in some detail.

The "transient" stability of a simple system is discussed, use being made of a new diagram known as the power angle diagram which may be derived from the circle diagram as obtained for static stability. Three diagrams are required for the simple investigation but the method may be elaborated to include all the factors affecting the problem including the characteristics of governors, exciter systems, and so forth.

The difference between the problems of switching operations, load swings and short circuits is pointed out. In the last case the effect of different values of ground resistance is discussed at some length and also the effect of length of time before circuit breaker opens.

The necessity of obtaining reliable data on ground resistance with faults is stressed.

Throughout this paper the essentiality of delivering the necessary kilovolt-amperes to the line either by adequate exciter systems or by proper modification of machine characteristics in order to maintain a high order of stability is insisted on.

It is pointed out in the Appendix that while inherently compensated generator, synchronous condensers, etc., are future possibilities, our main concern is the problem of getting the most out of present day designs as our present day problems depend on these and not on something that may be commercially developed five years from now. Consequently the conclusions refer to means that may be made quickly available and the two most important are:

a. Improved inherent regulation of machines.

b. Increased speed of excitation.

THE problem of stability of transmission systems has come up for considerable discussion during the last few years due to the fact that it has an important bearing on the future development of power in this country, particularly in localities where there already exist large concentrations of power which it is proposed to tie together by high voltage transmission lines.

The connecting links between these large distribution centers and generating points must be such that the resulting unified system has at least as good a performance as regards maintenance and reliability as the best of its constituents, and as a matter of fact to fulfill the hopes of its advocates this resulting system should show a better performance.

A principle which common sense seems to dictate in the early stages of a development, of such magnitude as this programme represents, is to carefully weigh all the factors which go to make a successful system. It is not incompatible with the optimistic spirit, which is part of the make up of the engineering profession, to weigh every factor carefully before taking the first steps because so much depends on the success of the first part of such a program. A blunder or failure to give the proper weight to such a factor as stability, might have very grave effects and set back the development programme for many years.

The old saying that "a chain is no stronger than its weakest link" may well be taken as a guide during the initial stages, and I think that good judgment dictates that these first links of our superpower chain, especially those that introduce new sources of power should be made as strong as we know how, at the present state of the art.

I wish to emphasize this point because there seems to be an inclination on the part of some engineers to underrate the importance of a careful study of stability, for the reason that large utilities today are operating satisfactorily and instability does not seem to disturb them. This reasoning is all the more dangerous because it is partly correct. The true reason why existing utilities are not troubled by instability is that when conditions of interconnection are met that tend towards instability, they are avoided either by giving up the advantages of interconnection or by strengthening the tie lines.

It is not safe to take past experience as a criterion on which to base superpower developments because of the necessity of maintaining service over the interconnecting lines, greater extent of the lines and greater amounts of power to be handled by the lines all of which factors are such as to increase the tendency to instability. As a matter of fact we know of a number of cases where instability has actually occurred and large systems have pulled apart causing more or less lengthy interruptions to service. How much more might the effect of the breaking apart of a large generating station from a superpower system be felt, especially in the initial stages, before the complete unified system has been achieved. I repeat, therefore, that it is not only good engineering practise but also good sense to make the first links of a superpower programme as perfect from all points of view as possible with the present knowledge of the art.

It is the object of the present paper to analyze the factors entering into the stability problem confining the discussion to the consideration of simple cases in order to avoid undue complexity.

General Review of the Subject

The attention of the engineering world has been drawn to the phenomena of instability as a result of actual experience in operation. The early cases naturally had to do with links between generating stations in distribution systems. I can recall some early cases of instability due to short circuits in feeders connecting large generating stations which were the cause of a good deal of speculation.

More recently there has been a tendency to connect large utilities together with a view to interchanging power in case of emergencies. Unfortunately these tie lines have been frequently of the type very aptly defined as "shoestrings" and have failed to carry out the purpose for which they were intended: In other words these shoestrings in themselves were unstable and could not tie the systems together. In many of these cases, fortunately, the reason for the tie was more sentimental than real and the systems tied together being self sufficient no harm was done when they broke apart. The case of a superpower interconnection would be another story and a break apart might be serious. We first became interested in this question as a result of a study of the possibilities of troubles due to connecting large hydroelectric generating plants through long transmission lines with large public utilities distributing power. This study has thrown a new light on this whole class of operating phenomena and a number of happenings which were in the past mystifying in the light of knowledge gained by this study have very simple explanations.

To cite a few examples we have all heard of the fading out of power from a hydroelectric source supplying a utility. We have also heard of power surges which appear to be of more or less harmonic character, that is to say, a generating plant has a period during which it alternately acts as a motor or generator. These cyclic changes may be relatively slow and will be indicated by the wattmeter which will swing in synchronism with the load changes. The system in such a case has already passed the point of stability although not infrequently the generator ultimately falls in step again. The effect on a large system may be quite serious as synchronous motors may be thrown out of step during the period of unstable operation.

In the case where the generating station has not passed the point of instability it may oscillate about the point of stable operation for several seconds, this being evidenced by oscillation of the station wattmeter until the ultimate operating position of the generator rotors is reached. These characteristics will be further elucidated after the elements entering into the problem of stability have been considered.

The first study of a phase of the problem of stability was made by the late Dr. C. P. Steinmetz. In his paper which was published in the 1920 Transactions of the A. I. E. E. he confined himself to the analysis of system troubles but did not give consideration to its aspect as a possible limitation in high voltage transmission.

The consideration of a superpower network extending over the Eastern States and perhaps eventually over a great part of the United States and Canada, has emphasized the importance of a careful study of the factors influencing the stability of large superpower systems with a view to controlling and improving the characteristics of the various units entering into the problem.

I take it that a criterion of operation must be set up for each portion of the superpower programme. It cannot all be carried out at once therefore each portion must conform to some standard of operation. What is this standard to be? I feel that all public utility engineers will be unanimous in insisting that each portion of the proposed program when completed and in service will perform this service with at least the same reliability as the best that has been obtained in similar existing power supply systems. By reliability I mean freedom from interruption and ability to deliver load at the proper voltage.

The nature of the standard set up for superpower lines will influence not only the type of line construction used but also the characteristics of the generators

and synchronous condensers. It may be necessary to look into the secondary transmission lines to insure that they do not prove to be the weak link in our chain. Where long transmission lines are involved intermediate synchronous condenser stations will prove economical provided that condensers of proper design are used.

It is necessary therefore in studying the stability of superpower systems to consider also the characteristics of generators, exciter systems, condensers, etc., to ascertain what type of design will prove most suitable for superpower extensions and will insure the highest degree of stability. Other apparatus such as circuit breakers, relays, etc., will have an influence on the problem, but the generator with its exciter and the synchronous motor are the fundamental elements in the problem of stability.

Electrically both generators and synchronous condensers are extensions of the main transmission line with somewhat different characteristics. But, as we know, transmission lines differ in characteristics, and no appreciable error is incurred by ignoring the distributed capacity in low-voltage transmission while in the case of 220 kv. it becomes of supreme importance. The same thing is true of generators and synchronous condensers, these may appropriately be considered as transmission lines having reactive impedance, (although saturation will affect the constancy of the reactance) if we have to consider only slow changes in load without regard to matters of stability; but when studying matters of stability, whether static or transient, both must be considered with reference to their exciter and damper windings so that the action becomes that of coupled circuits. The result of this is that any change in armature current sets up in the field current and damper winding changes in the currents which tend to annul the magnetic effect of the change in armature current so that the field tends to remain constant for a substantial period after the change takes place. If it were not for the resistance of field and damper windings, these transient currents would persist and the generator or synchronous condenser would be to a certain extent self-regulating. There would be a drop in terminal voltage due to the increase in load, however, due to the imperfect magnetic coupling between field and armature and this drop may be termed the leakage drop.

Since it is not possible to get away from resistance in the damper and field winding, recourse is had to an exciter system which builds up the field current faster than this induced current dies down. Thus the effect is the same as, or better than, what would be obtained if the field and damper windings had no resistance. It is possible to carry this method of compensation to the point where the terminal voltage remains substantially constant during sudden changes in load or other disturbances.

There are other ways of course by which similar results may be obtained, but these involve new developments whereas that cited above follows along standard well-tried lines.

The above, together with the transmission line, the characteristics of which are well known, constitute the electrical elements entering into the problem. There are other elements which come into our picture due to the fact that our generator, synchronous condenser, and the load are not only electrical transmission systems but also mechanical transmission systems having inertia and these systems are coupled with the electric system by a torque-speed or power coupling. This adds very considerably to the complications when we try to compute what takes place with a sudden change in conditions. We shall return to this subject later on when we look into the problem of transient stability in more detail.

I have enumerated above the physical and electrical characteristics of machines that enter into the problem of stability. In addition to this the problem is tied up with the action of the various relays such as those controlling the exciter voltage, the hydraulic relay devices controlling the gate opening, and the steam throttle governors, the relays controlling the operation of circuit breakers in cutting out sections of transmission lines when a ground or short circuit takes place. It will be obvious to engineers that to take accurate account of all these factors would be a hopeless proposition; so we proceed on the basis of ignoring such factors as appear not to influence the problem to any appreciable extent, as for example, the assumption is usually made for ransient stability that the power input to the generators remains unchanged during part of the disturbance, this is justified due to the extreme sluggishness of hydraulic governors.

TRANSIENT STABILITY

Much has been heard in recent years of stability but no clear and comprehensive definition of the term has been published. Stability may be defined as the capacity of a power system to remain in equilibrium under steady load conditions, and its ability to regain a state of equilibrium after a disturbance has taken place. The first part of this definition is referred to in this paper as "static stability," and the second part as "transient stability." It should be noted that after a transient disturbance, the system will not necessarily seek the original state of equilibrium.

The problem of stability is one of securing a proper balance between mechanical input to a generator and its electrical output, and the electrical input to a motor and its mechanical output, the electrical quantities being dependent on the characteristics of the machines and of the system as a whole. It is, therefore, an exceedingly complicated problem, involving mechanical factors such as inertia, governors, gate speeds, etc., and also electrical factors such as machine characteristics, line constants, breaker operation, etc.

The natural tendency of a generator connected to a

power system is to deliver electrical power equal in amount to the mechanical power delivered to its shaft less its own losses. This condition of equilibrium is satisfied when the counter-torque due to armature currents and field is exactly equal to the mechanical torque applied at the shaft by the prime mover. When such a situation arises that there is a difference in the mechanical and electrical torque, the generator either speeds up or slows down until a new position of equilibrium is reached; and during the transition stage, the inertia forces due to the moving masses act in a manner which tends to prevent any change in speed.

In thinking over these questions, it is well to consider all the aspects a generator or system of generators may take. It may be purely a generator or take on the characteristics of a synchronous condenser, or even of a motor. The torque on its shaft working as a generator, compels it to deliver sufficient power to equilibrate the applied power. In attaining this state of equilibrium, moving from the initial position where the machine acts as a synchronous condenser (no external load) to the position where it acts as a generator, the rotor is accelerated, so that when equilibrium is reached, the rotor, considered as a mechanical cyclic system, has advanced in phase. This advance in phase is just sufficient to cause the equilibrating current to flow as in a simple transmission line, so that the power input and output diagram of the generator would be exactly the same as that of a simple transmission line, if it were not for the effect of saturation and the effect of internal magnetic coupling during the transient state. The phase advance of the rotor is just equal to the phase angle between the terminal voltage of the machine and the component of internal voltage due to the direct current in the field. This phase angle, however, is not the true angle of advance for the reason that the electrical torque depends upon the action between armature current and the actual field—not a fictitious field. The actual field is produced not only by the field current, but also by the armature current.

When a change in input or output of a generator occurs, currents are set up in the field circuit and dampers which tend to maintain field and the voltage generated thereby at their original value. At the same time, the rotor takes up a new position, and in so doing, inertia torques are introduced which must also be taken into account.

The proper value of voltage to take account of in matters of stability is therefore the voltage set-up by the true field which is the resultant of the d-c. field current, induced field currents, damper currents, and the armature currents; this is the e. m. f. actually generated by the field and which is required to establish equilibrium between electrical and mechanical torques.

Let us analyze the problem with a simple system, assuming a generator supplying power to a synchronous motor over a two-circuit transmission line as indicated in Fig. 1. For the steady-state condition, there will

be a phase angle between the internal e. m. fs. of the generator and motor. This angle is a function of the load, and in general varies in the manner shown in Fig. 3, which is known as a "power angle diagram." In the diagram, let P_0 represent a particular input to the generator. For this input, α_0 is the angle between the generator and motor e. m. fs. for the steady-state condition, or point of equilibrium.
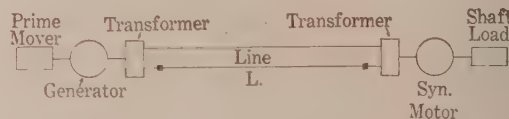
Fig. 1

It will be noted that it is possible to obtain another solution corresponding to α' which is, however, an unstable solution. Let us consider a small increase in the angle α beyond α'. This will cause a corresponding drop in the output, and consequently since the input is constant, the generator will accelerate and increase the angle of advance, the effect being cumulative. In the case of a small decrease in the angle α from α', the generator will slow down or move in the direction of α_0. A similar analysis shows that α_0 is a point of stable equilibrium, because small displacements from that point will set up forces tending to restore the system to the point α_0.

It is evident from the diagram that the load can be increased to the value indicated by P_s which represents the static limit for the circuit assumed, and with the generator and motor voltages maintained. While there is a definite static limit dependent on the circuit characteristics and on the voltage conditions, there is no well defined limit for transient stability. In fact, it is necessary to specify both the load and the magnitude of the disturbance in order to determine the transient stability limit.
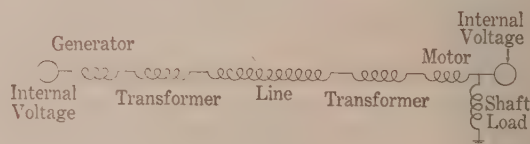
Fig. 2

If the system is operating with the power input P_0 and a disturbance takes place, causing the angle α to increase beyond the value α', it will be unable to recover itself, even though the disturbing force has been removed. In general, the disturbance will affect the generator and motor in different ways, consequently it will be necessary to employ two power angle diagrams in studying conditions during disturbances, one representing the generator end, and the other the motor end of the system.

The principal conditions of operation tending to produce instability in a power system are as follows:

   a. Line switching.
   b. Load swings.
   c. System faults.

As an example of line switching let us consider the simple system shown in Fig. 1 and Fig. 2 and assume that line L_1 is opened at either end. In this case the
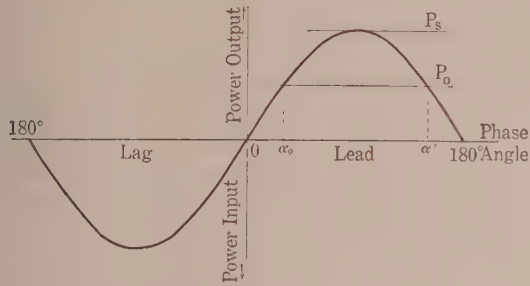
FIG. 3—ANGLE DIAGRAM OF SIMPLE POWER SYSTEM BASED ON CONSTANT VOLTAGES AT BOTH ENDS

power angle diagram may be represented as shown in Fig. 4, for the condition before and after the switching operation. Let us assume that the power input to the generator is P_0 and that the original steady state angle is α_0. After the switching operation the new position of equilibrium will be reached at α_0'. When the system is operating at α_0 the opening of the line L_1 reduces the power that will be taken over the system at that angle by the vertical distance between the power input curve and the new output curve. The power represented by
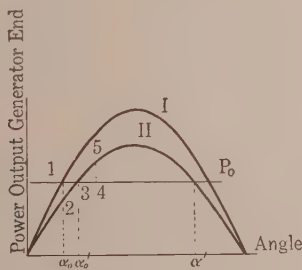
FIG. 4—ANGLE DIAGRAM OF SIMPLE POWER SYSTEM FOR SWITCHING OPERATION

    Curve I   Initial condition
    Curve II Condition after switching

the distance point 1 to point 2 represents that consumed in accelerating the generator rotor. Because of this acceleration the angle α will increase along the new curve towards point 3. As it approaches point 3 the accelerating force will decrease and the velocity will increase until at point 3 the accelerating force will be zero and the velocity a maximum. As a result the rotor will overshoot towards point 5, a retarding force being set up which will increase as the point 5 is approached. At point 5 the velocity will be normal and the retarding

force a maximum tending to bring the rotor back to point 3. The amount of the overswing will be such that the area 1 2 3 equals the area 3 4 5 except for the damping action due to losses. Because of the losses the swings will become smaller and smaller oscillating about the final position α_0'. For the case considered the system is stable since the overshoot does not carry it beyond the point α'.

Load swings differ from switching operations in that the circuit constants remain substantially the same and
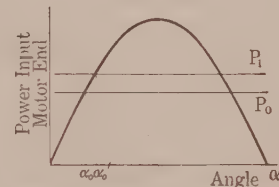
FIG. 5—ANGLE DIAGRAM OF SIMPLE POWER SYSTEM FOR SUDDEN INCREASE IN LOAD

the input and output vary, whereas, with switching, the input and output remain substantially the same and the circuits constants are changed. Considering again Fig. 1, and assuming that the load is increased as indicated in Fig. 5 from P_0 to P_1, if the increase is suddenly applied, the prime mover governor not responding immediately, the increment of power will have to be supplied by the kinetic energy of the system, slowing it down. This action will cause the governor to act and restore the speed to normal by increasing the input to
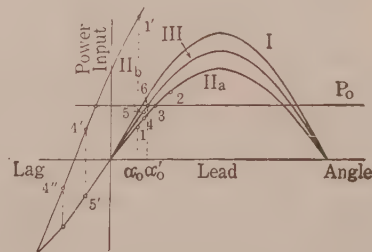
FIG. 6—POWER ANGLE DIAGRAM FOR SHORT-CIRCUIT CONDITIONS

    Curve I   Initial condition
          IIa Low resistance fault
          IIb High resistance fault
          III Final condition after fault is cleared

the system to correspond to the new output. Initially, however, there will be a disturbance due to the falling back of the motor with respect to the generator increasing the angle α between them, and there will be an overswing similar to that described in connection with the switching operation in Fig. 4. The generator and motor will oscillate with respect to each other but together will slow down towards the new angle of equilibrium α_0'.

The change of power input by governor action will in general necessitate the use of several power angle diagrams to properly represent the intermediate steps.

Short circuits present considerably more complications than switching operation and load swings due to the fact that three distinct networks are involved:

a.   The original condition prior to the application of the short circuit.

b.   A second condition while the short is on the system.

c.   A third condition when the fault has been cleared, usually by a switching operation.

The second condition is what makes the short circuits radically different from switching operations or load swings.   The short circuit may increase or decrease the power input according to whether it is a high or low resistance fault.   A high resistance short circuit usually occurs in the form of a fault to ground in a grounded neutral system.   There is a certain resistance for which the power increase will be a maximum.

The effects of the two types of shorts are indicated in Fig. 6.   Let Curve 1 represent the power angle diagram for the initial conditions with P_0; α_0 as the point
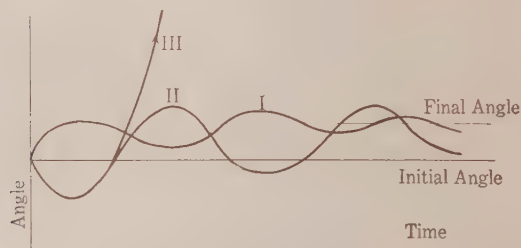
FIG. 7—ANGLE-TIME DIAGRAM OF SIMPLE POWER SYSTEM

   I   Switching Conditions—Stable
   II   High resistance fault—Stable
   III   High resistance fault—Unstable

of equilibrium.   Curve I I_a will represent the conditions with a low resistance fault applied to the system.   An oscillation will be set up about point 3 between 1 and 2 as described previously when considering switching operations.   The circuit breaker may open at almost any point during this oscillation, for example at point 4. The opening of the breaker immediately modifies the circuit conditions and a third network is set up of which the power angle diagram may be represented by Curve III, the power output being changed from point 4 to point 5.   In general the transition from the network of II_a to the final network of III will be accompanied by a second oscillation due to the fact that either the angle initially will not correspond to α_0', the angle of equilibrium or the velocity will not be such as to satisfy the condition of equilibrium, the system will therefore oscillate about the point of equilibrium, point 6 in the diagram.

In the case of a high resistance fault it is possible for the power output of the generator to be greater than

the input as indicated by the Curve II_b.   In fact power may be drawn from the receiver end of the system to supply part of the energy absorbed in the fault, for which condition the angle becomes negative.   The sequence of events is similar to that previously described for the low resistance fault.   It will be noted that stability is indicated in case the breaker opens at the point 4' because the energy absorbed during acceleration (area under P_0) is less than the energy that can be given up during retardation (area above P_0).   Pull out would occur should the breaker open at 4'' instead of 4'.

It is obvious from these considerations that the fault resistance is of prime importance in the consideration of short circuits.   Unfortunately there is very little information available at the present time concerning the resistance of faults under high current conditions.

In the preceding discussion an attempt has been made to give a general picture of the phenomena of stability. Certain simplifying assumptions have been made which in the more general cases will require modification, for example, the mechanical inputs and outputs of machine are assumed constant.   When the actual values are known as a function of time suitable correction can be made.   In this connection it may be pointed out that the stability limit for transient disturbances could be increased if the governors were made to regulate the input to the generators to correspond more closely with their output.   Another simplifying assumption made in the above discussion is that of constant internal voltage of the machines.   The effect of this may be corrected for by drawing up several power angle curves for different voltage conditions.

In the determination of the angular swings of the system and the stability limit it is necessary to employ the point by point method of analysis, all the forces for each point being in equilibrium.   The computation of the changes in the values of internal voltage during transient conditions is best accomplished by the "two reaction method" which permits the utilization of different time constants for the two components of main field flux.   By this method it is possible to take into account the effect of cross-magnetization and also the effect of the excitation system.   The two reaction method also permits the determination of the mechanical rotor angle, which must be taken into account in the consideration of the inertia effect.

Power angle diagrams do not show time, therefore, for the final results, it is preferable to use curves, with time as abscissas, since stability depends upon factors which are functions of time.   The angle between the e. m. fs. at the two ends of a system or the variation in the angle as a function of time gives a very satisfactory criterion of stability.   These angle time curves will have the general form indicated in Fig. 7.   Curve I shows a switching operation; Curve II and Curve III show a short-circuit condition with a high-resistance fault. Curve II shows the breaker opening at such a point that stability is obtained and Curve III shows the

breaker opening at such a point that instability results as indicated by the continuous increase in the angle.

The object of this discussion is to review the principal factors entering into stability and to provide an adequate visualization of the problem. It is beyond the scope of this paper to go into the detailed calculations of the magnitude of system disturbances and stability limits. In this respect it serves as an introduction to a more detailed paper by Messrs. Evans and Wagner which is being prepared for the Midwinter Convention in 1926.

In the above rather cursory analysis of the factors involved in the problem of transmission stability I have tried to stress several important points which I repeat below:

1. Stability is a characteristic of an entire power system—not of any particular tie line, and in the determination of limits, it is necessary to have a complete diagram of the system with full data on connected machines, loads, etc. Care should be taken to select for consideration operating conditions which are likely to be the most severe from the point of view of stability.

2. The standard of service in a superpower system must be of the highest order. While it is recognized that stability cannot be expected under all abnormal conditions, in my opinion the stabilty criterion should be that synchronism be maintained under single-phase faults to ground followed by the switching out of the faulty section.

A method of analyzing stability is indicated, based on so-called "power-angle" and "angle-time" diagrams. These diagrams take into account both the electrical and mechanical transients by a point to point method. The changes in machine fields are computed by Blondel's two-reaction method, as this permits the separate determination of the two components of flux, which have different paths and different time-constants.

CONCLUSIONS

In conclusion particular attention is called to certain factors entering into the problem, such as, characteristics of machines, time required by relays and circuit breakers to open, speed of operation of governors, resistance in the ground faults and earth connections.

As a result of the above analysis the following methods of increasing stability suggest themselves.

a. Improved inherent regulation of machines which can be obtained without greatly increased cost.

b. Increased speed of excitation; this possibility was discussed at the Philadelphia meeting of the A. I. E. E. in connection with the paper by Messrs. Bush and Booth.

c. Modification of the prime-mover governor more closely to regulate the input to the generator in accordance with the requirements of the transient, thus reducing the mechanical oscillations.

d. Development of a high-speed breaker and relay system to reduce the oscillations subsequent to the opening of the breaker.

e. Reliable data on ground resistance are very much needed, particularly under conditions of high fault currents. I would like to enlist the co-operation of public utility engineers in obtaining this information, as the value of ground is one of the controlling factors in the problem of transient stability.

f. The calculation of transient stability is, at best, a very tiring and long drawn out job. In view of the importance of making such computations in the case of every important branch or connection of the proposed superpower system, every effort should be made to reduce the labor involved in these computations. If an artificial model can be devised which will supply all the factors in their right relationship with one another such a method of solving problems will be welcomed. A purely mathematical solution seems out of the question as the problem when reduced to the simplest form involves elliptic functions. Very few engineers are sufficiently familiar with these functions to be at ease in handling them.

I wish to express my appreciation of the help extended to me by Messrs. R. D. Evans and Powell in writing this paper and by Mr. Dovjikoff in making the sketches and checking the text.

Appendix
Review of the "Static Stability"

INTRODUCTION

In the papers presented at the 1923 Midwinter Convention at Philadelphia by my colleagues and myself we confined our attention to the phenomenon of stability which has been termed static stability. There was some criticism of these papers on the grounds that they did not cover all there was to be covered in regard to stability of transmission systems. I think that I have said enough as to the elements that enter into the problem to indicate how hopeless would be any attempt to cover the subject generally in one paper and I may say in passing that this paper makes no pretense to go into details on any part of the problem but is more in the nature of an introduction to a paper by Messrs. Evans and Wagner which is in preparation for the next Midwinter Convention. The static stability problem appeared to be the stability problem in its simplest form and it seemed to us appropriate to begin the study of stability by a series of papers on this limit to the operation of transmission lines. That this is one of the important limits in operation under emergency condition is evident from the following statement by Mr. H. A. Barre in an article by him published in *The Electric Journal* June, 1925.

In designing a long high-voltage transmission line, careful consideration must be given to its stability, because the economic load and the ultimate carrying capacity of the line are of the same order. Studies of the Big Creek line indicate that, with only a single line in service the ultimate carrying capacity under steady load conditions should be about 180,000 kw. at the generator end.

On one emergency, this condition was actually reached. One whole line was taken out of service on a Sunday for maintenance work. About six o'clock in the afternoon the load built up very rapidly to 183,000 kw. when the synchronous apparatus at the two ends of the line went out of step. The voltage dropped nearly to zero, hovered there for awhile and then gradually built up to normal. About fifteen minutes later the load again built up to 183,000 kw. and the whole performance was repeated. Soon after the voltage came to normal the second time the other line was switched into service and there was no further trouble. So far as we know, this is the first time that a long high-voltage line has passed through this unstable condition.

The static stability limit will depend upon two conceptions. The first has to do with inherent stability and is based on the assumption that the regulator system is too sluggish to act before the transient current which tends to counteract the demagnetizing effect of the armature current has died out. This is the same as assuming constant excitation. The second considers the proposition that the dying out of the transient is so slow that the regulator has in general time to get into effect before the field has had time to change appreciably so that the limitation is set not by the synchronous impedance of the generators motors and condensers but by the leakage impedance, which should also include the leakage set up by the induced rotor currents. This is the same as assuming constant internal voltage.

There has been a great deal of discussion as to the proper basis on which the static stability should be
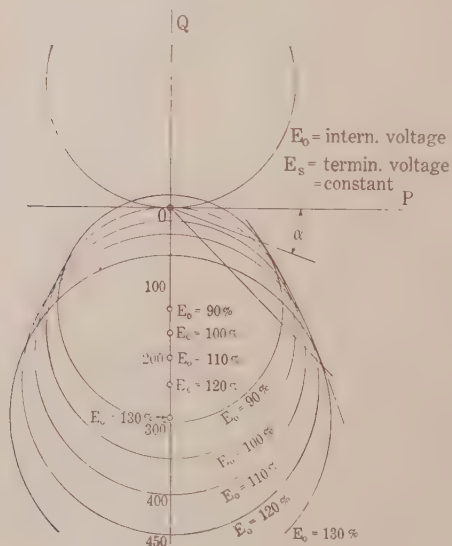
FIG. 8

determined. It has been argued that the synchronous impedance is the controlling influence but tests up to date indicate that this assumption is much too pessimistic, the second condition appears to be a reasonable assumption provided the rate at which excitation is required is not in excess of the ability of the exciter system. Several propositions that are necessary to a proper understanding of the subject will now be given consideration.

1. *An inherently compensated generator has no power limit.* This of course is an ideal that would be impossible in practise since internal heating would always be present in a practical machine. Several methods have been proposed for the internal compensation of generators, which are theoretically correct, but from a manufacturing point of view impractical. Even if such a generator were practicable the limitation of prime mover governors would make it of doubtful value. It is, however, a useful ideal to keep in mind when considering problems of stability.
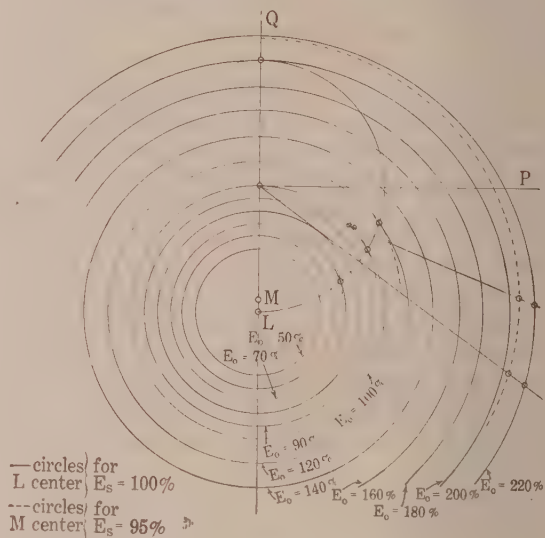
FIG. 9

2. *A generator having a fixed value of excitation will have a power limit depending on the nature of the load.* This power limit depends upon the value of the terminal voltage obtained under load and is therefore larger for leading power factor loads than for lagging power factor loads. The quantity entering into the terminal voltage regulation is the synchronous impedance which will vary with the field saturation and therefore is a rather crude quantity to use, but it serves quite well in illustrating the problem of stability qualitatively. If the load varies in power factor in such a way as to maintain constant terminal voltage as well, the load limit is quite definite and is obtained by a circle diagram of the same form as that for a simple transmission line. If we make a family of such circles (Fig. 8) using different values of terminal voltage, the loci for loads of constant power factor are lines drawn from the origin cutting the circles and stopping at the envelope returning back again to the origin. The power limit when the power factor is fixed is therefore the value of the load indicated by the intersection of this line with the envelope.

3. *A generator having its internal voltage fixed will have a load limit depending upon the nature of the load.* The same comments as in the case of proposition (2) applied here with the added statement that the actual

load limit will depend upon the ability of the exciter system to maintain this constant field during changes of load.

Static Stability of Generator and Load. (*A dead react-ive load*). A generator excited in the usual way will be stable for loads having only fixed resistance and inductance and the terminal voltage of the generator will be maintained constant within the limits of the capacity of the exciter system. During the transient stage, following an increase in load, there will be a fall in terminal voltage due to the leakage reactance of the generator, but this will be corrected as the exciter builds up the field. During the first transient stage, the field is kept practically constant by the corrective currents flowing in the field circuit and in the damper windings. The relation between internal voltage of the generator and the load may be easily obtained (Fig. 9) by drawing the power output circles for constant terminal voltage of the generator with varying internal voltage, drawing the locus for a constant power factor load which is a straight line drawn from the origin inclined at $\cos^{-1} \alpha$ to the axis of X. It will then be seen that, while the diagram indicates no limit, if we superimpose on this diagram a similar diagram for the same values of inter-nal voltage but for a terminal voltage slightly less than the original value (Fig. 9), the power circles of the last diagram corresponding in internal voltage to that of the first will not always be outside the first, showing that an increase of admittance will result, after a certain load, in decreasing power at a given power factor, with the internal voltage considered constant. The condition when the first circle is wholly outside the second takes place in the neighborhood of $E_0 = 2 E_s$ and for values of E_0 above this there will be a tendency for the voltage to dip on application of additional load of any power factor.

Dead Load with Leading Power Factor. In the dia-gram just given, the generator is assumed to have practically no resistance, so that the center of the con-centric system of circles lies on the Y axis; the following construction, however, holds for generators and motors having resistance. If a circle is drawn having its center at the origin passing through the center for $E_s = 100$ per cent this circle is the locus of intersection for the circles having the same value of E_0 but slightly lower value of E_s with the system of circles representing $E_s = 100$ per cent.

The Cartesian equation of the system of circles given in Fig. 9 is given by

$$(P_s - E_s^2 g)^2 + (Q_s - E_s^2 b)^2 - E_0^2 E_s^2 (b^2 + g^2) = 0 \tag{1}$$

In this equation the values $E_0 \, E_s$ are parameters, fixed values of these quantities giving one of the members.

Let us consider the system $E_s = $ constant; the sys-tem is a system of concentric circles with center at the point $P_s = - g E_s^2$; $Q_s = - b E_s^2$. If now we consider E_s to vary somewhat from its fixed value let us say diminish slightly, the family of circles for the diminished

value of E_s will intersect the other family of circles at certain points which will have significance because at these points the value of power delivered will be stationary because with increased admittance the volt-age will tend to drop as fast as the current increases, the value of E_0 being considered fixed.

To obtain the locus of these intersections differentiate (1) with respect to E_s and equate to zero, this gives us

$$2 g (P_s - E_s^2 g) + 2 b (Q_s - E_s^2 b) + E_0^2 (b^2 + g^2) = 0 \tag{2}$$

Eliminating E_0^2 between (1) and (2) we have

$$P_s^2 + Q_s^2 + E_s^4 (b^2 + g^2) - 2 E_s^4 (b^2 + g^2) = 0$$

or

$$P_s^2 + Q_s^2 = E_s^4 (b^2 + g^2)$$

This is the locus of intersection of contiguous circles; $E_s = $ constant when E_0 is the parameter and represents the loci of intersection of contiguous members of the family when E_s is considered to decrease slightly. It is a circle having the origin as center and which passes through the center of the family of concentric circles.

The circle touching the origin represents the condition of equality between internal and terminal voltage and all the circles that lie within this circle represent the condition of load in which the internal voltage is less than the external voltage; this condition can only occur at leading power factor. It will also be observed that where a line from the origin touches one of the circles, this represents a double solution and all such solutions lie within the circle locus. All points of intersections between constant power factor loci and the circles for $E_s = 100$ per cent contained in this region within the circle locus represent loads that are essentially stable in character, whereas the values obtained outside this region are inherently unstable, for the reason that an increase of load does not take place naturally since the circle for a slightly lower terminal voltage and the same value of internal voltage as existed before the in-crease falls within the corresponding circle for the original terminal voltage and this same value of internal voltage. This illustrates the reason why under certain conditions the natural regulation of a system may be-come quite bad so that there is a tendency to produce a slump in voltage when additional load is thrown on, so fast that the exciter cannot keep up with it. If, how-ever, the characteristic of the load is such as to give more leading current, or what is the same thing less lagging current, with decrease in terminal voltage the stability is greatly increased.

Induction Motor Load. This does not differ essen-tially from the dead inductive load discussed above but the tendency to slump in voltage after a certain load may be so marked that the exciter will not be able to cope with it and as a result the motor may fall in speed below its pull out point.

Synchronous Motor Load. Assuming that the termi-nal voltage is maintained constant we shall have three methods by which this may be done.

1. By generator field alone, synchronous motor excitation being kept constant.

2. By synchronous motor field alone, generator field being kept constant.

3. By varying both generator and synchronous motor field so as to get the best results.

The circle diagram for the input to a synchronous motor with constant terminal voltage is similar to that of a generator with constant terminal voltage except that the center of the circles is on the opposite side of the origin. In fact if the internal impedance of the two machines is the same the motor circles are the images of the corresponding generator circles with respect to a line passing through the origin at right-angle to the line joining the centers of the generator and motor circles which also passes through the origin.

For the condition of constant internal field in the motor, the circle corresponding to this field strength is the locus for the power input to the motor. The generator circles passing through these points give the generator field required to maintain the terminal voltage at the given value. It will be readily seen that a limit to the amount of power that can be delivered is quickly reached.

For the condition of constant field of the generator the proper generator circle is taken, and the same comments apply as for the first case.

Next let us consider the case in which both machines are regulated; this must follow some specific scheme as both machines cannot regulate to maintain voltage.

For the condition of constant power factor the power factor line gives the locus of the points of intersection of motor and generator power circles which will give the proper field strength for this condition with each value of load.

Mathematically, if unity power factor is taken, for an ideal generator and motor, that is to say, machines having no resistance, there is no limit to the amount of power. Actually the limit is set by the exciter system, for when the internal or field voltage reaches a certain value indicated by the circle of intersections more power cannot be taken by the motor or delivered by the generator without an increase in the field strength of either or both machines. This may be shown graphically by drawing the circle diagram for the two machines based on this value of field voltage and varying terminal voltage, it will then be seen that the only solutions possible under these conditions, give lower values of power. Therefore, further demand on the system must be supplied by an immediate increase in field strength. or else the characteristics of the motor changed so that it delivers more leading current as the voltage decreases,

This condition does not necessarily imply instability but it indicates that without the aid of the exciting system a further increase in load admittance may be sufficient to cause the two machines to fall apart and this might also happen if the exciter system were too sluggish.

The point I wish to emphasize in this discussion is that the stability of such systems depends on the ability of the system to inherently supply the necessary wattless power required to meet the sudden demand for power; fortunately, except under abnormal conditions, the demand is relatively slow and plenty of time is given for building up the field to supply the necessary wattless power.

The interposition of a transmission line still further limits the load that can be transmitted between the two systems. I wish to take this opportunity to correct a statement that has repeatedly been made to the effect that the distributed capacity of a transmission line compensates the reactance of the line. It is true of course that at light loads it causes a rise of voltage along the line but it also increases the range of regulation and increases the tendency toward instability. It does not cut down the size of synchronous condensers as much as is popularly believed because the total range of regulation of the machine is increased, requiring lagging kv-a. at light loads and leading kv-a. at heavy loads.

To determine the static stability of a system consisting of generators, transmission lines and synchronous motors on the assumption that the voltage is held constant at the sending and receiving end of the transmission line, the circle diagram of the transmission line at the receiving end is drawn, and the power circles of the input to the motor are also drawn to include the step-down transformer impedance on the same scale and superimposed on them. The same thing is done for the sending end with the generator. Several values of field voltage of the motor are then taken and the corresponding value for the generator are obtained in the usual way from the second diagram. The circles for constant field voltage of this value with varying value of terminal voltage are then drawn with the corresponding value of transmission circles for both sending end and receiving end assuming simultaneous reduction in terminal voltage at each end. If the value of power input remains stationary for a slight decrease in terminal voltage the point of instability is indicated. Another procedure is to construct the circle diagram for the whole system including the generator and the motor leakage reactances checking up with the complete generator diagram; that is to say, the input of the generator considered as part of the transmission system and the output of the motor considered the same way. If maximum output is indicated for either machine with constant internal voltage this will be the point of instability.

I have dwelt some time on the problem of static stability because it is a necessary introduction to the main problem, that of transient stability as it contains a number of the important elements required in the consideration of the transient stability problem. I have particularly considered the synchronous motor for

the reason that the characteristics of most supply systems can probably be fairly well expressed by a modified form of a synchronous motor load.

Fig. 1 shows the generator, transmission line and synchronous motor in the form of a diagram. Fig. 2 shows the simplest form of power system in the form of an electrical diagram. In this diagram the internal voltages of the collective machines reduced to a common voltage is expressed by a figure in a circle. It is

apparently not a far cry from the first form of circuit to the second. *The main requirement is to obtain an equivalent system which will give the same voltage wattless power characteristics as the system under investigation.* It is important to obtain reliable data on the characteristics of systems that are to be connected to a high-voltage transmission line as the character of the loads will have a great deal to do with the stability of the transmission line.

Electricity's Progress in the Iron and Steel Industry

By Committee on Applications to Iron and Steel Production[1]

AT the first meeting of this Committee held in the Schenley Hotel, Pittsburgh, Pennsylvania, September 17, 1924, every member being present, it was agreed that the Annual Report for 1924-25 should be a topical consideration of progress during the current year, and the field was duly apportioned to the several members of the Committee.

One of the papers secured by the Committee and deserving of special mention in this Report is that, prepared and presented by Mr. K. A. Pauly before the Annual Convention at Pasadena, California, September 1924, entitled "Contributions of Electricity to the Steel Industry."

It was also agreed that each member of this Committee should actively interest himself in arranging for one or more joint meetings of the Local Sections of the A. I. E. E. and the Association of Iron and Steel Electrical Engineers (A. I. & S. E. E.).

Although many members of this latter organization are also members of the A. I. E. E., your Committee was of the opinion that closer cooperation and unity of interests might be brought about by the formation on the part of the Association of Iron and Steel Electrical Engineers of a committee empowered to act directly with your Committee in all matters relating to the mutual interests of the two organizations.

This matter was brought to the attention of your Board of Directors, who, on September 26, 1924—

VOTED: That the Board of Directors recognizes the importance of the work being carried on by the Association of Iron and Steel Electrical Engineers in the industry with which it is associated, and appreciates the desirability of closer cooperation between the Institute and the A. I. & S. E. E., and requests its

Committee on Applications to Iron and Steel Production to consider and report to the Board methods of cooperation between the two organizations and means of bringing it about.

This action on the part of the Directors was duly transmitted by this Committee to the Board of Directors of the A. I. & S. E. E., who, through an incomplete appreciation of the objects in view, at first rejected this suggestion. Further consideration, however, has resulted in the consent of the Directors of the A. I. & S. E. E. to give the proposition more thorough study before taking final action.

Every twelve month period shows the steady and truly remarkable, if not always spectacular, increase in the application of electricity in the manufacture of steel. The current year of 1924-25 has been no exception. Generally speaking, however, the growth has been along lines already well defined and presents little that is fundamentally new or novel.

I. GENERATING UNITS

The Steam turbine continues to hold first place as a prime mover in the steel plant. That there has been a substantial increase in the generating capacity of steel-mill power plants is evident from the fact that one manufacturer reports the sale during this past year of fourteen units ranging from 750 to 15,000 kw. and aggregating 111,000 kw.

It is an open question, however, as to whether the greater economies which are being sought throughout the industry may not, together with improved design of engines and gas cleaning equipment, bring the slow speed gas engine back into favor. The economic value of blast furnace gas is increasing, due to its successful use in various metallurgical processes, soaking pits, heating furnaces, etc. This increasing value will automatically necessitate its use at the highest possible efficiency and as a given quantity of gas can be converted into more kw-hrs. of electrical energy through a gas engine than when burned under a boiler, the return of the gas engine, in spite of its present high first cost and maintenance charges, is a possibility.

Very satisfactory progress is being made in the development and use of Diesel Engine units up to 5000-kw. capacity.

II. DISTRIBUTION

No marked improvements in distribution have been reported, but the use of purchased power has rapidly increased as the size and reliability of commercial power systems has increased. Largely for this reason, 60-cycle current now predominates.

Automatically controlled railway and power sub-stations have been in successful operation for several years, and during the past year there have been installed several such equipments in steel plants. One large steel plant has changed over all of its manual stations, involving five motor-generator sets and a large number of a-c. and d-c. feeders, to full automatic control. At another plant a full automatic substation has been installed to control two 1000-kw. motor-generator sets and all a-c. and d-c. feeders. A third plant has installed three equipments for the operation of motor-generator sets and feeders. This increase in the use of automatic substation control has been due primarily to the extreme reliability of operation, together with the operating saving that can be shown, as compared with manual control, to take place where power is used, thereby reducing the line losses in the feeder circuits.

III. MAIN-ROLL DRIVES

To an even greater extent than usual, this past year has been marked by a replacement of existing engine drives by modern electrical equipment. The sturdy induction motor still meets, in some one of its several forms, most requirements for main roll drives, except for reversing mill duty where, of course, nothing is likely to replace the d-c. machine with generator field control.

The growing demand for high tonnage mills with great flexibility in range of product is, however, requiring more and more adjustable speed, d-c. motors and this in turn is giving more importance to the relative merits of motor-generators, rotaries and mercury-arc rectifiers as a means of transforming from alternating to direct current. For certain types of mills the synchronous motor is being considered very favorably, although no installations of importance have as yet been made.

The following tabulation includes only main-roll motors on a continuous rated basis in units above 300 h. p. as reported by the three principal electrical manufacturers in this country up to June 1, 1925.

	1923	1924	1925
60 cycle	452840	478390	543440
25 cycle	475825	490225	538450
Direct current	299670	324860	430610
Totals	1228335	1293475	1512500

It is interesting to note that out of 95,225 h. p. reported by one company as sold during the year units (13) totaling 23,750 h. p. or approximately 25 per cent of the total represents motors which have been purchased to replace existing steam engine drives.

For the operation of a continuous skelp mill there has been purchased a 7500-h. p. induction motor with Kraemer speed regulating set to adjust the speed of this motor from 250 to 134 rev. per min. This is the largest motor with Kraemer equipment that has ever been built.

Another manufacturer reports the construction of a 5000-h. p., 75/150-rev. per min. motor for reversing service built with a single armature and supplied at 700 volts from two generators in parallel forming a part of a three-unit set.

This is a distinct departure from the usual practise of having several armatures connected in series where units of this size are involved. This motor replaces an engine on a 48 in. universal plate mill.

Other notable units reported by this manufacturer are:

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2—3500 h. p.—50/120 r. p. m.—700 volt—reversing units
2—5000 h. p.—25/150 r. p. m.—700 volt—reversing units
1—5000 h. p.—50/120 r. p. m.—700 volt—reversing unit
4—7000 h. p.—50/120 r. p. m.—700 volt—reversing units
1—8000 h. p.—40/80 r. p. m.—700 volt—reversing unit
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Physically, the 7000 h. p. motors are the largest single armature reversing motors yet built and the 8000 h. p. will be, when completed, approximately 50 per cent larger. This latter motor will drive a 54 in. blooming mill which is likewise the largest mill of the kind in this country.

Another notable installation is reported by the same manufacturer, namely, a tandem hot-strip mill driven by one 1500 h. p. induction motor and six individual adjustable speed d-c. motors with an aggregate rating of 10700 h. p. for the d-c. machines which are of the compensated type.

A strong and sturdy yet easily operated foot-master switch has been developed for the control of reversing mill motors. The use of a foot-operated master switch requires one less operator in the mill pulpit than with a hand-operated controller and some mills have also found that production is increased as the concentration of control to one man permits closer coordination of the various operations.

Two speed regulating equipments of the frequency converter type are being built for use with existing 600 h. p. motors.

Truck-type switching equipment is being used to a greatly increased extent in many mills. Less time is required for assembly in the field, greater safety is secured as live parts are better protected and shutdowns are fewer as a spare truck may be kept available to quickly replace a damaged one.

IV. AUTOMATIC CONTROL

An interesting tendency in auxiliary mill-motor control is toward the use of time limit acceleration

instead of current limit which has long been the accepted standard. In one system the time interval between the closing of successive accelerating contactors is secured by an ingenious application of the well-known principle that when a constant d-c. potential is applied to a circuit containing inductance, an appreciable time elapses before the current reaches its maximum value.

Another control system recently placed on the market secures the time element of acceleration by the delay in building up or down of a magnetic field, when the relay coil is short-circuited, a definite time is required for the flux to decrease to a point permitting the release of the relay armature. This armature is forced out by a spring of adjustable tension which, together with other features, gives a timing range of 0.2 to 2.0 seconds for the relay. Once adjusted, this timing remains constant under all operating conditions.

In one case where this control was substituted for a series-contactor control, the current peaks were reduced from nearly 800 amperes to a maximum of approximately 350 amperes. This reduction in current peaks is due to the fact that, with the series-contactor control, it is necessary to set the contactors to close at a relatively high value of current in order to take care of maximum load conditions which are encountered when a mill is first started. This adjustment usually is not changed after the mill has been limbered up, and as a result the motor and control are forced to handle all loads with the same effort as required for the maximum load. With a definite time control, the motor is forced to exert its maximum torque only when the load conditions demand it.

V. Yard Electrification

The search for the best all around system of yard transportation continues slowly because of the excessive investment charges. Installations now in operation for two years or more seem to have demonstrated conclusively that a third-rail system can be operated successfully in a steel-plant yard without excessive maintenance charges or danger to employees. The first cost is high—approximately one dollar ($1.00) per foot of trackage electrified.

The development of the Diesel Electric Locomotive for this purpose is proceeding very satisfactorily. When production permits reasonable first costs, its very attractive operating characteristics will undoubtedly bring it into general use in steel plants.

VI. Electric Heating

With the expiration of patents covering certain alloys of great value for use in resistor units, the development of annealing and heat-treating furnaces has received marked impetus. Furnaces of large capacity with temperatures of 1800-2000 deg. fahr. are being installed in considerable numbers.

Two electric furnaces for the continuous hardening, quenching and tempering of carbon-steel wire have been recently installed in wire mills. This process results in a higher quality of wire than when treated in a gas-fired furnace. A bright unoxidized surface on the wire is produced. These are the first electric furnaces to successfully do this work and have proven economically desirable as well as producing a more satisfactory product.

VII. Arc Welding

The use of arc welding as a means of repair of worn and broken parts in steel mills has shown a great increase within the past year. The savings effected by arc welding of a single worn or broken part in a number of cases more than paid for the first cost of the welding equipment. A number of steel plants are using the automatic arc-welding process for the building up of worn shafts and similar operations.

VIII. Electric Furnaces

Conditions in the development of "arc furnaces" for melting steel and iron have become fairly well standardzied, both as to installed kw. per ton, voltage between electrodes, etc. Continued investigation of the two-voltage system of operation, a high voltage for melting followed by a low voltage for refining, indicates that there is no deleterious effect on the product while there is a decided saving in the power and electrode consumption, together with the time required to make a heat.

In this field, there continues a steady, if slow, development of low frequency "induction furnaces" for making high grade steels and alloys, but the field of high frequency induction furnaces has witnessed one of the most interesting developments of recent years.

For many years it was thought that the high frequency induction furnace could not operate successfully in melting metals at frequencies lower than 5000 cycles. However, it has recently been demonstrated that frequencies approximating 500 cycles will melt metals on a commercial basis with very good efficiency. For instance, common brass has been melted starting with a hot crucible with power consumption of approximately 225 kw-hr. per short ton—and other metals in proportion.

The equipment is simple, consisting of a motor generator set taking power from standard power circuits and supplying approximately 500-kw. single-phase to the furnace. The furnace consists of a standard clay graphite crucible, as developed for steel melting, with heat insulating casing around which is placed an edge-wound copper strip coil. To the terminals of this coil is applied 900 or 1800 volts at 500 cycles, single phase; a capacitor unit being connected across the coil in order to bring the power factor up to approximately 100 per cent.

In view of this recent development, no definite data are available, but it is confidently expected that this condition will be changed in time for the next report.

The Study of Ions and Electrons for Electrical Engineers

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THE present paper is presented as a contribution to the educational activities of the Institute. Education is often an art and never completely a science. With respect to ions and electrons the science is new and the development of the art scarcely begun,—an art that is bound to undergo rapid evolution. The value of the present paper at best can only exist temporarily.

Physicists and chemists in their studies of the foundation of matter during the last quarter century have been profound students of ions and electrons. Virtually all of their discoveries and results are of direct or indirect value to electrical engineers. The technical and practical uses of knowledge of this character today are extensive. Many important developments have been possible only by its means. And such developments have encountered difficulties that in turn have defined the great need of further knowledge of the same general character. The need for the electrical engineers is being formed up, however, in an entirely different mold from that which shapes the requirement of the more general science worker.

In many of the problems originating nowadays in the electrical industries wherein ions and electrons are involved, the physicists and chemists are, in all ordinary circumstances, so loaded with necessary duty in the solution of their own problems that they can rarely afford the time and facilities to come to the aid of electrical engineers. The electrical engineers can, therefore, no longer depend largely upon the physicists and chemists for enhanced results that will enable them to solve their own problems of this class. They will have to do their full share from this time forth to extend knowledge of the facts in regard to ions and electrons and their behavior.

It is of corresponding importance that all advanced students among the incoming generation of electrical engineers be reasonably well equipped with an understanding of the present-day expediency for attacking problems encountered in the electrical industries that require for their solution a clear understanding of the behavior of ions and electrons. It is also recognized that advanced students are not always young men in the colleges. It is important that all,—old and young, —wherever situated, should know that it will be most helpful to them and to the electrical industries to acquire a well-founded knowledge of ions and electrons and how to take advantage of every opportunity to apply or to extend such knowledge.

Millikan has splendidly summarized existing knowledge of electrons and ions in his book on The Electron[1], more especially from the point of view of the physicist. J. J. Thomson[2] has rendered a similar service from the point of view of the chemist, though himself a physicist. To these recent classical treaties the advanced student, at the threshold of the subject, is referred.

The following are some of the fundamental facts in regard to electrons that must always hold the attention of many electrical engineers: There are two varieties of electrons, distinguished primarily by the signs of their respective electric charges. The quantities of these charges are alike for each,—4.78 by 10^{-10} electrostatic units, or 1.59 by 10^{-20} ampere-seconds. In respect to other attributes they differ decidedly. The mass of the negative electron is 1/1845 that of the hydrogen atom,—the lightest of all atoms. Correspondingly, the mass of the positive electron is approximately 2000 times the mass of the negative electron, or nearly the same as that of the atom of hydrogen. In atomic structure the positive electrons behave as though they and some of the negative electrons formed the atomic nucleus, while the rest of the negative electrons associated with an atom behave as though they were set in orbits about the nucleus. So far as is known, positive electrons do not exist in the free state. They exist only within the nuclei of atoms accompanied by some of the electrons that bind them in close proximity by electrostatic attraction. The numbers of positive and negative electrons present in the same neutral atom are equal.

The spontaneous breaking up of the nuclei of the heavy (radioactive) atoms into helium atoms and negative electrons is the nearest known approach to the existance of free positive electrons. On the other hand, free negative electrons exist in abundance. An almost endless variety of physical or physicochemical actions may break their orbital bonds to their corresponding atomic nuclei and set them free. The removal of a negative electron from an electrically complete or "neutral" atom results in the presence of one free negative electron, ordinarily called *electron* and an atom carrying the positive charge of one electron. Such an atom is ordinarily referred to as a *positive ion*. Under all ordinary conditions approaching quiescence, free electrons adhere to atoms, otherwise neutral. The bond is weak and easily broken when the atom is

1. For all references see bibliography appended hereto.

driven electrically or mechanically through gases, fluids, or near the walls of solids.

All conduction of every character is now known to be due to the movement of positive and negative electrons or more simply ions or electrons, or both. The electrons or ions may be moved mechanically, electrically or electromagnetically. An example of their movement electromagnetically is encountered in the electron jet cyclograph, wherein the electrons liberated from a hot cathode are driven forth in a jet by a strong electric field, and the jet is then deflected transversely by a magnetic field.

It follows that the mobilities of electrons and ions through solids, liquids, gases and empty space are factors of the highest importance. Far too little is known about these mobilities. Physicists, however, have determined them as the velocities of positive and negative ions in electric fields of unit strength in air and in hydrogen at the usual density occurring at a temperature of 15 deg. cent. and a pressure of 76 cm. as follows:

Mobilities in cm. per sec. in unit fields, i. e., one volt per cm.		
	ions	ions
Air..............		
Hydrogen.......		
Air.............	0.35	1.83
Hydrogen........	6.1	7.8

For practical purposes the relations of these mobilities to their corresponding fields of strength may be assumed to be linear for the time being.

Correspondingly, all non-conduction must be due to one of two things,—the non-movement of all ions and electrons present or their total absence. Materials through which ions or electrons can be moved freely are designated as conductors. Materials through which ions and electrons can not be moved are designated as true insulators.

With the new understanding of electrical phenomena, it is helpful to distinguish three sorts of conductors and corresponding conductions.

I. Metallic conduction—due to the free movement of electrons from atom to atom, requiring no e. m. f. for their detachment and only that e. m. f. which is required to supply the heat absorbed through the increased atomic agitation that has been produced.

II. Electrolytic conduction—the free movement of ions through an ionized liquid (or salt solution) from anode to cathode and vice versa, using an e. m. f., part of which is consumed positively or negatively in detaching or attaching ions at the electrodes in dissociation and recombination of the electrolyte and for the rest in supplying the inevitable heat due to the increased mechanical molecular agitation.

III. The movement of free ions or electrons in a non-ionized fluid. Conduction of this type is dependent upon two factors: (1) A requisite source of ions or electrons and, (2) the e. m. f. required to overcome the counter e. m. f. of space charges and again to supply the inevitable heat.

Fluid conduction may be set up in every kind of fluid, liquid or gaseous. No fluid of any sort pervaded with a supply of ions or electrons can properly be regarded as an insulator. Correspondingly every fluid in which ions and electrons are absent must function as an insulator.

Amorphous bodies or the precooled liquids, such as glass, the matrix of porcelain, fused quartz, etc., should be remembered as belonging to fluid conductors. The hardness of these bodies is due to their high viscosities, occurring when they were cooled from the molten state without crystallization. Pure, normal sulphur is an example of a non-fluid or crystalline body free of ions that intercepts completely the flow of ions and electrons and functions, therefore, virtually as a perfect insulator. Fluids can have no such dependable barrier quality. This is the great reason why fluid insulators must always be supplemented with substantial barriers that break up the threadlike channels occupied by moving ions when driven by applied e. m. f.

Many have a feeling that air is a well-nigh perfect insulator or barrier to the passage of current forced along by applied voltage. The fact is that air has little or no barrier quality. If ions are liberated into the air, as by the passage of X-rays, on the application of a few volts only, the air may be observed to conduct with relative facility. It is actually no insulator in the sense that sulphur is. The great reason why air appears to function as an insulator in all ordinary cases is because of the absence of virtually all facility for liberating ions or electrons into the air.[8] To detach an electron from a metal electrode into a gas requires an electrical field terminating on the wall of the electrode that has been formed by the application of a million volts per centimeter. Above such voltage gradient terminating upon a conductor, air ceases to function as an insulator because the applied e. m. f. is sufficient to expel ions copiously from the one metal electrode, and drive them through the air to contact with the opposing electrode where they are discharged, thus completing the electric current circuit. At correspondingly lower voltages, the air will function as an insulator only because electrons can not escape from the conductor walls.

Because metals and carbon when raised to sufficiently high temperatures will radiate electrons and thus supply ions copiously, air in the presence of highly heated electrodes ceases to be an insulator and functions abundantly as a conducting medium.

We are thus compelled to recognize once for all that actually air and other gases are not really insulators—the thing that did the insulating, which was mistakenly attributed to the air, was actually a property of the wall of the conductor-electrodes by which electrons were confined within the conductor and not permitted

to escape into the air or other gases occupying the space between and surrounding the electrodes.

It is particularly in this "no-man's-land" of ions and electrons, wherein insulators are not insulators and conductors are not conductors, that the electrical engineer is much concerned today.

The most important of the expedients for liberating electrons are:

I.   From metal electrodes immersed in air or other gases

      a.   by heating the electrodes.

      b.   by applying ultraviolet light to the electrodes, for which some metals are more effective than others.

      c.   by coating the electrodes with certain salts that emit electrons copiously when heated.

      d.   by intense electric charges, 1000 kv. per cm. in air—1250 kv. per cm. in vacuum.

      e.   by evaporation or boiling of the metal or carbon electrodes.

II.   From gases by

      a.   exposing the gases to X-rays or by the emanations from radium and other radioactive substances.

      b.   Collision ionization, commonly called corona.

III.   From metals to fluids

Electrons pass out from the cathodes and into the anodes immersed in electrolytes by the phenomenon known as electrolysis, long since well understood through the activities of the chemist.

IV.   From metals to solids

Herein little is known as yet. There appears to exist no general understanding of the phenomenon of the passage of electrons from a metal to a non-conducting solid. Nevertheless, among the classical experiments of a century ago there was the one in which the metallic coatings of a "Leyden jar" were made removable. With the electrodes mounted the jar was charged. The coatings were then removed and the jar and coatings were examined to determine the seat of the charge. The coatings were discharged and replaced and the jar thereafter discharged as a whole, when it was found that the discharge was virtually as strong as if the coatings had not been removed, discharged and remounted. Through the new knowledge, we now know that when metal electrodes make good contact with solid dielectrics, electrons pass easily from the metal electrode to the atoms of the contacting dielectric and vice versa. The conclusion is inevitable that the contact e. m. fs. between the metallic and dielectric walls are extraordinarily low, permitting the easy exit of the electrons from the negatively charged electrode to the adjacent dielectric, and conversely from the dielectric to the positively charged electrode. Because in solid dielectrics neither electrons nor charged atoms can migrate with any but the slightest degrees of freedom, the dielectric functions as a barrier; an excess of electrons in the superficial face of the dielectric under the cathode and the opposite condition under the anode occurs and develops until the counter e. m. fs. of the bound charge thus produced balances the applied voltage whereon the action rests in a potential state.

V.   Liberation of ions and electrons is produced by friction, splashing of liquids and bubbling of gases through liquids.

Of the highest importance, likewise, are the facilities available for the quantitative observation of the causes and corresponding effects of the activities of ions and electrons. In occasional circumstances, the quantities to be measured are all suitably large, including the expenditures of power, for which there is at hand, a wealth of well-known measuring expediencies. Often, however, one or more of the essentials to be measured are relatively very small or very large and the corresponding facilities available are as yet few, if at all, and general experience in their use may be lacking.

For the detection and gaging of small free charges in the air and gases, the gold-leaf electroscope, the delicate electrometer or galvanometer are often necessary. New uses for the old expedient of the potential plate or potential electrode are being found for the determination of potentials due to position, potential gradients, voltage duties and potentials as modified by the presence of space charges. Conducting or non-conducting barriers in plates, tubes or other forms as required to limit the migrations of ions or electrons are often most helpful. A metal woven mesh, coarse or fine, may have its uses as a kind of "grid" for high voltage studies of the migrations of the electric carriers in air, gases and liquids. The modern cathode-ray oscillograph and electron jet recorder are of extraordinary value for the promulgation of these studies.

In many studies the time-relation wherein a thing happens within the duration of a cycle or transient is of dominating importance. In these cases some dependable criterion in time relation must be found. When the actuating voltage is cyclic or transient and maintained with the requisite power, the non-inductive, non-capacitive resistor for "tapping out" fractional replicas of the total actuating voltage is a valuable expedient herewith. The potential plate, judiciously used, is also a helpful expedient for the same purpose.

Studies of this character in one way or another require electric power supply-sources in almost every thinkable voltage-current-time relation. Herein for continuous high voltages the old electro-static machine and modern kenotron (the latter with requisite accessories) are available. Below and above commercial frequencies laboratory forms of alternators, and arc-converter and electron-tube oscillators are available,—the choice must be determined by the special circumstances.

In the aggregate, there must be provision for the use of almost every character of substance occupying the immediate space about the electrodes which in turn must be available in every required form taken with

respect to the method by which ions or electrons are to be detached from them. Among these electrodes there must be those which are made of boiling metals or carbon.

Henceforth, problems without number will come up for attention in the electrical fields, the solution of which will be feasible only through the use of abundant knowledge of ions and electrons to be acquired only by orderly, persistent effort. In closing, by way of example herein, one may mention the problem of the reduction of the damage done by power line flashovers. In a considerable percentage of these flashovers the trouble is started by indirect lightning, surges or other forms of over-voltages on some sort of attenuated conducting material laid across the circuit, usually from conductor to tower. In a great many of these cases the trouble is known to have had a very small beginning that now and then is not augmented and clears itself. But in the majority of cases the local metal faces of the conductor and tower are heated with great rapidity to the boiling point in those spots that happen to be located at the termini of the thin ion-electron stream that inaugurated the action. The ionized vapor liberated by the boiling that ensures enormously augments the conductivity of the original stream of electric carriers, resulting in the rapid development of a heavy short. An effective procedure for the solution of the problem may be to cover the conductors at the towers suitably with a heat resisting barrier that will not permit the discharge to terminate on the conductor in a sufficiently narrow spot to produce boiling so as to permit the action

to clear itself. It is not forgotten that in procedures of this sort not one but all perceivable options that promise a solution must be worked through at least to that point from which it is seen that they may or may not be given up effectively.

In conclusion, it should be helpful to all electrical engineers to acquire a knowledge of the more important factors in the behavior of ions and electrons; and for the maintenance of a well-balanced progress in the electrical industries, it is highly necessary that some of the electrical engineers acquire, augment and apply the highest attainable knowledge of this subject.

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7. *The High Voltage Wattmeter.* Joseph S. Carroll. Paper to be presented at the Pacific Coast Convention of the A. I. E. E., Seattle, Wash., Sept. 15-19, 1925.

8. a. *Air as a High Voltage Insulator.* A. I. E. E. TRANS., Vol. XXX, p. 29, 1911.

b. J. L. R. Hayden and C. P. Steinmetz, *High Voltage Insulation.* A. I. E. E. TRANS., Vol. XLII, p. 1029, 1923.

Precision Watthour Meters and High-Frequency Measurements

By Committee on Instruments and Measurements[1]

IN selecting subjects which would become the major study of the committee during the year, an effort was made to choose those which seemed to be lagging in progress because of unorganized attention, or to be only imperfectly coordinated and recorded because of their relatively recent development. Two subjects were chosen, one on each of these bases, and subcommittees (with chairmen, H. B. Brooks and C. M. Jansky

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A. S. Albright,	E. D. Doyle,	L. T. Robinson,
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Perry A. Borden,	C. M. Jansky,	Byron W. St. Clair,
H. B. Brooks,	P. M. Lincoln,	G. A. Sawin,
R. P. Brown,	W. M. McConahey,	Benjamin H. Smith,
J. R. Craighead,	Wm. J. Mowbray,	H. S. Vassar.

respectively), were appointed to make the survey.

One of these subcommittees has been assigned the task of promoting the development of a device or devices for the measurement of energy directly in terms of watthours under the condition of excessively fluctuating power, for averaging this variable power with laboratory precision, and to produce results equivalent in accuracy to those obtained with laboratory equipment now used for the measurement of volts, amperes and watts. The committee is not concerned with the watthour meter as used by the million in the vending of electric energy; that is the concern of other agencies, and it may well be agreed that the watthour meter, in practically all respects, surpasses the measuring devices through which the public purchases other services and commodities. But this device, or modifications of it, thus far produced and used as a precision standard of comparison in laboratory and field testing, and as a means of averaging

variable power over an extended time (as in water-rate determinations of large turbo-alternators, for example) leaves something to be desired.

The subcommittee charged with this problem realized that one of the outstanding sources of variation in accuracy of watthour meters was the variation in temperature of their component parts, arising from two principal causes; (1) changes in temperature of the ambient medium; (2) heating from the flow of current through the coils, and from iron losses. There was presented at the Mid-winter Convention an important paper by Messrs. Kinnard and Faus, in which temperature errors in induction watthour meters were analyzed theoretically and experimentally and a device described for the compensation of the major of the two principal classes of temperature errors. The subcommittee considered it of little or no value to assemble and coordinate data on the temperature performance of the meters in current use, which are not equipped with any such device, but that its concern should be with meters which include this or some equivalent compensation. When such meters are regularly available, the subcommittee will consider the feasibility of having exhaustive tests made by suitable authorities.

Meanwhile, there remains a number of other disturbing effects to be considered, such as the influence of frequency, voltage, and wave-form variations, and of low power factor. These matters, and the methods by which improvement may be realized, will be included in the work of the subcommittee. The program thus briefly outlined will obviously involve a considerable amount of effort over a long time, and the subcommittee looks with confidence to the experts of the manufacturers, and others who specialize in this field, for full cooperation in the task.

The watthour meter, in different forms, has not been found entirely suitable for measuring the power output of large turbo-generators during water-rate tests and there is a tendency to prefer the wattmeter for this purpose, even in spite of the necessity of taking a very large number of readings during the progress of the test. The scope of the subcommittee's work includes a study of this method also, and by request, a valuable paper on the "Measurement of Electrical Output of Large Turbo-generators During Water-rate Tests" has been prepared by E. S. Lee; this paper was assigned to the program of the First District Regional Meeting at Swampscott in May. It was hoped that this paper would serve to bring out discussion which would be of value to the subcommittee in its further study of the problem.

The phenomenal development of radio communication naturally focussed the attention of the committee on the subject of electrical measuring instruments for use with frequencies in the audio and radio ranges. It seemed to be an opportune time to make a survey of the available instruments for these fields, their operating principles, limitations, and scope of applicability, and a second subcommittee was appointed to conduct the survey.

The most extensive use of high-frequency measurements is undoubtedly in the field of radio communication. However, frequencies ranging from 20,000 to 50,000 are much used in wire telephone and telegraph communication and in the so-called "wired wireless" or "carrier current" communication over power transmission lines. Another possible application of high-frequency measurements is the determination of the periodicity of transients and the measurements of higher harmonics on power lines and in electrical machinery.

Low values of inductance and capacitance are of great importance where high frequencies are involved. The power engineer has heretofore considered them negligible. With a better knowledge of high-frequency measurements, quantities that have been neglected may assume greater importance even in power engineering. These low values of inductance and capacitance are usually measured by some resonance method; that is, by "tuning" the circuit with the unknown inductance or capacitance to the frequency of another circuit with known inductance and capacitance and then calculating the unknown quantity in terms of the known values.

There are two common methods of measuring resistance at high or radio frequencies; the reactance variation method, and the resistance variation method. The application of the reactance variation method requires a knowledge of the frequency used. It is, therefore, more useful in measuring logarithmic decrement and sharpness of resonance. Bridge methods are but little used for the measurement of resistance at radio frequencies but a somewhat similar method, which utilizes a differential transformer, is coming into use. There is also the method employing a voltmeter designed for accuracy at radio frequencies.

Great need has been evidenced for the development of more accurate measurement of resistance, inductance, and capacitance at high frequencies, but there is greater need for the more general utilization of instruments of adequate accuracy for measuring the frequencies of the electromagnetic waves emitted by radio-frequency generators used in broadcasting and other stations. These frequencies are usually measured by means of an instrument known as a frequency or wave meter. The extensive use of certain radio-frequency bands requires that radio stations be assigned frequencies which are, in some cases, only 10,000 cycles apart. If there is to be no interference between stations, each must maintain its assigned frequency within a small fraction of one per cent; there is a call for the development and use of frequency meters having the degree of accuracy required for this purpose.

This subcommittee is also continuing its studies.

Accuracy of Alternating-Current Test Instruments

BY S. C. HOARE[1]

Associate, A. I. E. E.

Synopsis:—The paper deals mainly with the accuracy of instruments used under maintained conditions of load. Well designed voltmeters, ammeters, and wattmeters show very small errors due to self-heating and changes in ambient temperatures. Iron-vane ammeters are described which have small errors due to direct-current hysteresis and changes in wave-forms.

PRECISION a-c. instruments are today expected to meet demands for accuracy almost unthought of a few years ago. This applies particularly to acceptance and water-rate tests, which require maintained accuracy of instrument indication over long periods of time,—several hours. Compared with the d'Arsonval types, the a-c. instruments have relatively higher internal losses, and are more apt to be susceptible to error due to maintained conditions of load. It is the purpose of this paper to set forth some of the errors to be expected and show how well some modern instruments meet the exacting requirements.

Instruments for field service must incorporate sturdiness of construction with a torque sufficiently high to insure dependable behavior, provided the two features are not incompatible with good sensitivity and low losses. By torque, we refer to the absolute value and not necessarily the torque to weight ratio, though the latter must receive some consideration. It is not so much the torque to weight ratio, but torque itself which determines the life of accuracy in an instrument, other things being equal.

An instrument can be no more constant in indication than are its control springs, and we accordingly begin with springs and treat of the various factors tending to cause errors.

SPRINGS

A great deal of development work has insured that, with careful selection and treatment of the bronze, a control spring which is almost ideal can be made. This is fortunate inasmuch as other instrument refinements would be of little value with springs possessing appreciable "set" and "fatigue" characteristics.

Well made and properly mounted springs do not show "set" in instruments having the usual 90-deg. scale angle, and "fatigue" amounts to less than one minute of arc. This applies to the most severe conditions of stress, and means that the pointer should return to zero within one thickness of its thin knife-edge immediately after release from a four-hour 90-deg. deflection. With the ordinary four-inch pointer, the

deviation from zero would not be greater than about 0.004 in., barely perceptible.

The temperature coefficients of both elasticity and resistivity, while not small in value, are, however, quite definite and can be compensated for in the layout of the various circuits of the instrument.

TEMPERATURE ERRORS

Present day demands are such that the precaution of removing instruments from the circuit after reading cannot always be observed. Instruments must, therefore, indicate, with good accuracy, continuously, over a period of hours instead of minutes. This requires among other things a consideration of the effects of temperatures due both to self-heating and to ambient changes.

We do not generally expect errors due to changes in mechanical dimensions, but some instruments do have a tendency for stickiness with an increase in temperature. This is due to the high expansivity of the shaft which makes it "freeze" in its jewel bearings. This especially applies to shafts of aluminum or its alloys. The defect could, of course, be corrected by setting the shaft loose in its jewels, but with a risk of "wobbly" and uncertain indication under normal temperature conditions. A better way is to use material of low expansivity.

The factors most apt to cause errors during sustained conditions of load has been that of inconstancy of the control springs. Though not always the case, many instruments today have springs of a quality which precludes further consideration of spring inconstancy in this paper.

Temperature effects, however, are inherent to all but the electrostatic types and offer a more serious problem. The elasticity of the control spring decreases about 0.04 per cent per deg. cent. rise in temperature at ordinary room temperatures, and by this amount, tends to make the instrument indicate high. The potential circuit, consisting of windings of copper or aluminum, in series with a "swamping" resistor, is increased in resistance with a rise in temperature. This makes for a lower instrument indication. The two effects tend to compensate each other to a degree, depending upon the proportion of windings and series resistor in the potential circuit.

At ordinary room temperatures the windings increase in resistance by about 0.4 per cent per deg. cent. rise, and the series resistor remains practically constant in value. If the circuit is adjusted so that the resistance of the windings is one-tenth that of the whole circuit, then its resistance will increase 0.04 per cent per deg. cent. rise. It might seem that this proportion would effect perfect compensation for effects of the control spring. However, due, to different rates of heat dissipation, it is generally necessary to use other circuit proportions than that of 1 to 10, depending upon the make and type of instrument.

In wattmeters, the resistance of the moving coil may be too low to effect any great degree of compensation. Thus, they may indicate high with increase of temperature. The comparatively high proportion of windings
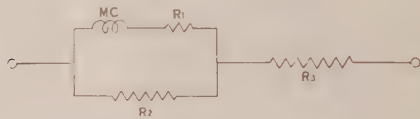
FIG. 1

resistance to total resistance,—unavoidable in voltmeters,—tends for overcompensation, and it is, therefore, found that voltmeters may indicate low with temperature rise.

Ammeters of the iron-vane type are inherently of a high-torque, which permits us to use windings of few turns and consequential low resistance. The self-heating errors are, therefore, small and we may expect errors due only to changes in ambient temperature.

The sign and magnitude of temperature errors in a-c. instruments may, therefore, vary with different conditions of load, instrument connections and room temperatures. The errors are largely eliminated by careful design and construction. Features receiving

FIG. 2

special consideration are, (a) internal losses and overload capacities, (b) proportion of component parts of the various circuits, and (c) compensating circuits.

Accuracy of indication under sustained loads is not attained at the expense of other desirable features as, for example, high torque, low internal-phase angles, and low frequency and wave-form errors. Such compensating schemes as we find necessary to apply must vitiate none of these important features.

A common form of compensating scheme used both wattmeters and voltmeters is that given in Fig. 1. Here MC denotes the moving coil and R_1, R_2 and R_3 non-inductive, non-capacitive resistors. Effective compensation is secured with the proper values of both resistance and temperature coefficient of resistance of

R_1 and R_2. The arrangement is not, however, critical of adjustment. If the initial error in the instrument is positive, (as is often the case in wattmeters), then we may make R_1 of copper wire, and R_2 of wire possessing a negligible temperature coefficient of resistance. The
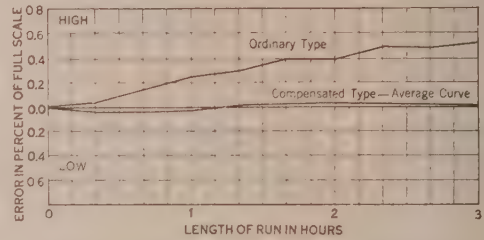
FIG. 3—ELECTRODYNAMIC WATTMETERS
Variation of instrument indication with time under maintained load conditions

effect of an increase in temperature then, is to reduce the current in the moving coil by the amount necessary for compensation. In voltmeters the circuit constants would be interchanged.

Though effective in compensating for temperature, the circuit of Fig. 1 is almost certain to cause in wattmeters large and indefinite inductive errors. The shunting of the moving coil branch with the relatively low resistor R_2 may cause serious errors due to mutual inductance. It is not generally possible to secure good temperature characteristics with R_1 and R_2 of resistance values high enough to avoid complications due to phase angles.

This form of circuit should be reserved for voltmeters. Voltmeters are not sensitive to small differences of phase-angle between moving coil and field coil currents.

For wattmeters, the series method of compensation given in Fig. 2 is preferred. It is equally as effective as the shunted arrangement and does not disturb the internal phase-relations of the instrument. R_1 in this case is a small copper wire resistor placed near the spring.
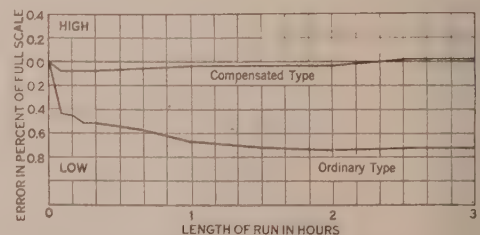
FIG. 4—ELECTRODYNAMIC VOLTMETERS
Variation of instrument indication with time under different maintained load conditions

The curves of Figs. 3, 4 and 5 contrast the performance of some compensated instruments with those of the ordinary types. The curves for wattmeters show first, the initial dip due to increase in resistance of the moving coil, and second, as heating continues, the

upward trend due to decrease in elasticity of the spring. Finally, as the compensation becomes more and more effective the curves gradually flatten out.
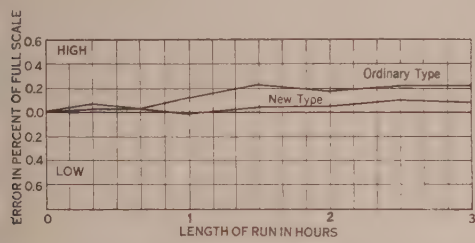
FIG. 5—IRON-VANE AMMETERS

Variation of instrument indication with time under maintained load conditions

The curves for voltmeters show much the same characteristics, though the effect of the spring is inconsider-
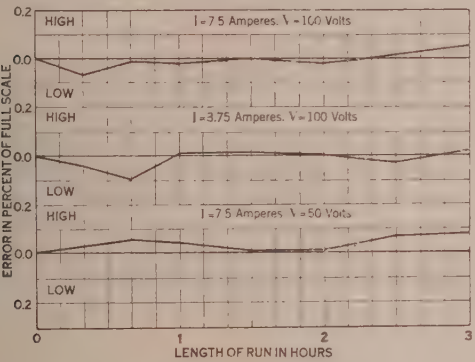
FIG. 6—ELECTRODYNAMIC WATTMETER

Variation of instrument indication with time under different maintained load conditions

able. Figs. 6 and 7 are indicative of what may be expected in good instruments when used under widely
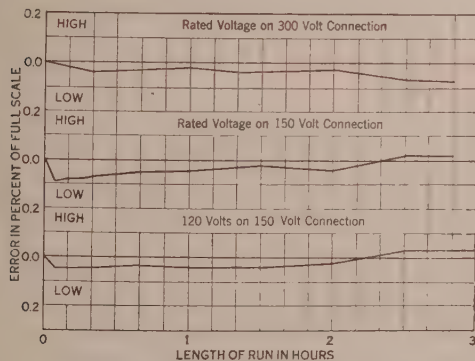
FIG. 7—ELECTRODYNAMIC VOLTMETER

Variation of instrument indication with time under different maintained load conditions

different conditions of loading. Errors observed with one deg. cent. rise in ambient temperature are given in Table I.

TABLE I

	Ordinary Type	Compensated Type
Wattmeters	+ 0.03%	+ 0.006%
Voltmeters	− 0.005%	+ 0.007%
Ammeters	+ 0.02%	+ 0.016%

INTERNAL PHASE ANGLES

These are due both to self inductance in the potential circuit and to mutual inductance in the windings. We

FIG. 8

are concerned ordinarily with the effects of phase-angles in wattmeters when used on circuits of low power factor, though it is also possible for voltmeters and ammeters to show errors due to phase-angles. Voltmeters and ammeters in which are incorporated certain compensating circuits can be quite sensitive to variations in both frequency and wave form due among other things to incorrect "time constants" of the circuits.

Mutual inductance effects are negligible in well constructed instruments, and in fact the only possibility of errors from this cause lies either in short-circuit turns in the windings or in the use of low voltage connections in instruments designed for higher voltages,
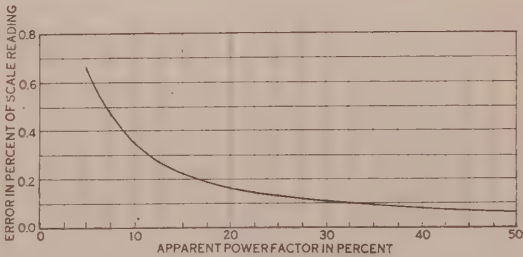
FIG. 9—ELECTRODYNAMIC WATTMETER

Variation of calculated inductive correction with load power factor Corrections to be added for leading current; subtracted for lagging current

i. e., the results of a 30-volt connection in the ordinary 150-volt instrument should be regarded with suspicion. Wattmeters compensated for temperature with the shunted arrangement of Fig. 1 are very apt to show errors due to mutual inductance.

Low phase-angles are, of course, very desirable but it is equally desirable that such as do occur be definite and amenable to calculation. Eddy currents

induced in metal frame-work and certain temperature compensating circuits tend to give uncertainty both to sign and magnitude of the inductive errors. The multiple connection employed in the current winding to obtain higher ratings may add further complications, due to inequalities. Equality, which is necessary to avoid the presence of parasitic currents in the circuit, is more nearly approached with the multiple connection of two distinct conductors, than with two separate coils. Fig. 8 illustrates how equality is obtained in a high-capacity wattmeter current winding. Well designed
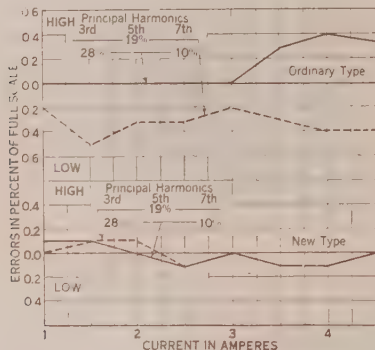
FIG.   10—IRON-VANE AMMETERS
Variation in indication due to irregular wave form

series resistors are, for all practical purposes, both non-inductive and non-capacitive, though in some of the older forms capacitance predominated with the resulting complications.

A representative curve of inductive corrections for a wattmeter is given in Fig. 9. It is computed for 60 cycles.

FREQUENCY AND WAVE FORM

Except for induction errors, wattmeters are insensitive to variations in commercial frequency and wave form.

The relatively high self-inductance of voltmeters involves a careful consideration of their "time constants" if they are to be used interchangeably on direct- and alternating-current circuits. There should be no detectable variation in indication between mean reversed direct-current and an alternating-current of 60 cycles. In terms of 125 cycles, the variation ought to be no more than 0.05 per cent,—barely perceptible. Voltmeters of the electrodynamic type are unaffected by ordinary wave distortion, provided they are free of frequency errors.

The iron vane ammeter, though practically insensitive to variation in commercial frequency was, until recently, quite susceptible to changes in wave form. The use of new magnetic materials enables us to reduce errors from this cause from about 0.5 to 0.1 per cent. (Fig. 10.) These errors refer to wave forms having prominent third and fifth harmonics.

HYSTERESIS ON DIRECT CURRENT

Shielded wattmeters and voltmeters of the electrodynamic type show no differences in indication with reversal of direct-current if the shields are free of permanent magnetism. Extreme overloads may, however, give to the shields a definite magnetic polarity, and it is well to check the instruments occasionally for this condition.

Previously, the iron-vane ammeters were very susceptible to magnetic hysteresis, and the variation in indication with reversed direct-currents was great enough to prevent even a fair degree of accuracy. The magnitude of these errors depends upon the previous history of magnetization of the iron. Aside from the ordinary form of hysteresis, due to changing polarity and magnitude of the magnetic flux, the iron is also susceptible to changes in direction of the flux through it. We may call the latter "rotational hysteresis." Instruments having the irons mounted eccentric to the shaft exhibit effects of rotational hysteresis to a marked degree.

New and specially prepared magnetic materials now enable us to construct iron-vane ammeters having little hysteresis error. Errors of two per cent so frequently observed in this type have been reduced to about 0.3 per cent (Fig. 11). For alternating-current work it would appear that the present-day iron-vane ammeter is a very dependable instrument. In view of the improved wave-form and hysteresis characteristics, this type is to be preferred over the low-torque and high-impedance type employing the shunted, moving-coil
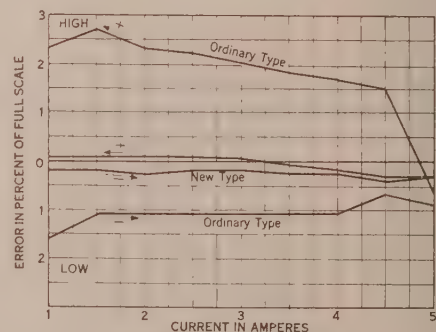
FIG.   11—IRON-VANE AMMETERS
Variation in instrument indication with direct-current showing effect of magnetic hysteresis

principle. The latter type is of course useful in the laboratory in making a-c. = d-c. comparisons. Laboratory standard ammeters are, therefore, of the shunted electrodynamic type.

STRAY-FIELD ERRORS

High-grade a-c. instruments are sufficiently well shielded to prevent errors from stray fields under ordinary conditions. Possibility of error in instrument

of high-current rating is remote if we use twisted conductors.

A field of 20 gauses "in-phase" is equivalent to about 100 times the horizontal component of the earth's magnetism, or the field 12 inches distant from a long straight conductor carrying 3000 amperes. In shielded instruments, this field should cause no error greater than about 0.4 per cent of full scale. With ordinary conditions of use, stray-field errors would than be undetectable. In general, we find that the higher-torque instruments are the least affected by stray fields, which is an argument for high torque.

To eliminate eddy currents and hysteresis, the shields are built of well-insulated laminations. Low power-factor errors in wattmeters have sometimes been traced to eddy currents in the shield. Improper methods of bolting the laminations together may be responsible for these errors.

The shunt compensating scheme of Fig. 1 in the paper is due to Swinburne (1887) and the series scheme of Fig. 2 was suggested by Dr. H. B. Brooks in his paper "The Accuracy of Commercial Electrical Measurements," (A. I. E. E. TRANSACTIONS, Vol. XXXIX, part 1, p. 517). A complete and comprehensive treatment of the effects of self- and mutual-inductance is given in this paper of Dr. Brooks. Reference is also suggested to C. V. Drysdale's paper upon the subject of inductive errors and given in the *Electrician* (London), Vol. 46, pp. 774-8, 1901 and Vol. 76, pp. 523-5, 1916.

The Quadrant Electrometer
BY W. B. KOUWENHOVEN*

Member, A. I. E. E.

Synopsis.—*The quadrant electrometer has long been recognized as a valuable instrument for measuring power in a-c. circuits, especially at low values of the power factor. Nevertheless, it has been used but little. This has been caused to some extent by the fact that Maxwell's treatment does not hold for all electrometers, and by the difficulty of determining its constant with alternating current.*

In this paper, the author has discussed the theory of the instrument from the point of view of power measurements and has reduced its general equation to a simple form. He has shown how its constants may be determined with continuous current, and that these constants also apply in a-c. power measurement. He has checked the theoretical calculations by experiments. Data of the determination of the constants of a given instrument with continuous current are given in the paper, as well as examples of the use of the instrument in the measurement of power in a number of alternating circuits having different characteristics.

THE quadrant electrometer has long been recognized as an instrument possessing excellent characteristics for the purpose of measurement. Nevertheless, it has been used but little. To a great extent, this has been due to the fact that its theory is not available in any one place, but one must search in foreign publications[1] to find it. With this instrument, it is possible to measure small alternating voltages and currents; also small amounts of power at very low values of power factor.

I. THEORETICAL

The instrument depends upon electrostatic repulsions and attractions for its torque. It consists of a needle or disk, cut in the shape of a figure eight, and suspended by means of a conducting fibre in a cylindrical metal box, cut into four equal quadrants. The needle and the quadrants are all mounted inside of a metal case, which protects them from external fields.

The case is fitted with a window through which the motion of the needle may be observed. The needle and the quadrants are insulated from each other and the case, and the latter is provided with leveling screws

The theory of this instrument was developed by Maxwell,[2] who obtained the relation

$$D \theta = (P_1 - P_2) \left(N - \frac{P_1 + P_2}{2} \right) \qquad (11)$$

Where

N = Needle Potential
P_1 = Potential of quadrant No. 1
P_2 = Potential of quadrant pair No. 2
D = a constant according to Maxwell
θ = deflection

The deflection of the electrometer depends upon the forces of attraction and repulsion between the charges on the needle and the quadrants, and the counter torque produced by twisting the suspension. Orlich and Schultz[3] showed that the D in Maxwell's equation is not a constant except for very small deflections and for some special electrometers. In most electrometers D varies with the needle potential and the potential difference between the quadrants, and when the electrometer is used as a deflection instrument, this variation must be taken into account.

There are at least two reasons for the variation in D. The first is that the directing force changes as the needle deflects. The second reason for the variation in D is

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1. For list of references see end of paper.

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caused by the fact that the quadrant electrometer is very sensitive to small differences of potential when used in quadrant or power connection. Contact differences of potential exist between the needle, the case and the quadrants. If we let

p_0 = contact potential difference between needle and case

p_1 = contact potential difference between quadrant No. 1 and case

p_2 = contact potential difference between quadrant No. 2 and case

Then

$$N = V_0 + p_0$$
$$P_1 = V_1 + p_1$$
$$P_2 = V_2 + p_2$$

where V_0, V_1 and V_2 equal the outside potentials applied to the needle, quadrant pair No. 1 and quadrant pair No. 2 respectively.

Taking these into account the torque equation of the
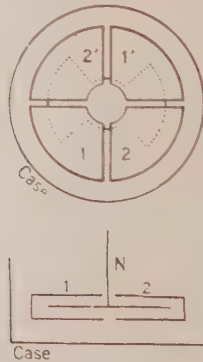
FIG. 1—QUADRANT ELECTROMETER

electrometer was derived and the result is given below:

$$\theta \left[1 + R\,(V_0 - V_1)\,(V_0 - V_2) + S\,(V_{12} - V_2^2) \right]$$
$$= a_0 V_0^2 + a_1 V_1^2 + a_2 V_2^2 + b_1 V_0 V_1 + b_2 V_0 V_2$$
$$+ c_0 V_0 + c_1 V_1 + c_2 V_2 \qquad (18)$$

Here R, S, a_0, a_1, a_2, b_1, b_2, c_0, c_1 and c_2 are constants whose values may be determined experimentally.

The D of Maxwell's equation (11) equals the terms embraced in the brackets of equation (18) and it is no longer a constant, but varies with the potentials applied to the needle and quadrants. The right hand side of equation (18) contains four terms corresponding to the four terms of Maxwell's equation (11) and in addition to these, it contains an $a_0 V_0^2$ term and three terms, $c_0 V_0$, $c_1 V_1$ and $c_2 V_2$, which depend upon the contact potentials, and are not included in equation (11). Equation (18) is the general equation of the quadrant electrometer. This equation will be further simplified in the experimental work that follows:

A study of equation (18) shows that there are two controlling forces present in the quadrant electrometer. These are the mechanical control produced by the torsion of the suspension and the electrostatic control

caused mainly by lack of symmetry in the instrument. The presence of the electrostatic control is indicated by the terms embraced in the brackets of equation (18). The algebraic sum of these two controlling forces opposes the deflecting torque set up by the applied potentials. By proper adjustment and construction, the electrostatic control may be made to add to the restoring torque of the suspension, to vanish entirely, or to neutralize the suspension torque. This last condition is used in the Compton Electrometer[1] to increase
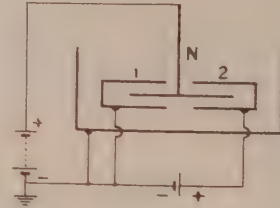
FIG. 2—CONNECTIONS FOR ADJUSTING THE HEIGHT OF THE ELECTROMETER NEEDLE

its sensitivity. In power measurements it is usual to reduce the effect of electrostatic control to as low a value as possible.

SETTING UP OF THE ELECTROMETER

The setting up of the electrometer may be divided into four parts:

1. Leveling. Remove the case and sighting through the quadrant slits, level in one direction. Turn through ninety degrees and level again. Continue turning and leveling until the instrument is perfectly level in all directions.

2. Setting horizontal position of needle. Bring the needle in position so that it is bisected by the quadrant
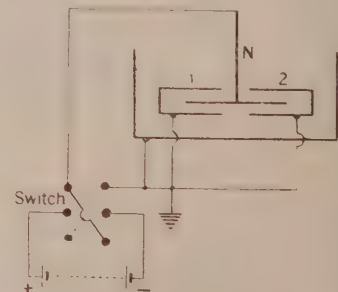
FIG. 3—CONNECTIONS FOR BRINGING THE MECHANICAL AND ELECTRICAL ZEROS INTO COINCIDENCE

slits and adjust its height until as nearly as can be determined by the eye, it is midway between the quadrants. Replace the case and make the final adjustment for the horizontal position. To accomplish this, connect both quadrants to the case and to ground and apply a high continuous positive potential to the needle. Note the deflection. Then reverse the continuous potential, making the needle negative, and

note the deflection. Adjust the horizontal position of the needle with respect to the quadrant slits until the two deflections are equal. The needle is then accurately centered horizontally.

3. Adjust for height. Apply a high continuous potential to the needle and a small continuous potential between the quadrants as shown in Fig. 2. Adjust the height of the needle until the deflection is a minimum. The needle is then midway between the quadrant faces.

4. Adjust so that the mechanical and electrical zeros coincide. Connect both quadrants to the case and to ground and apply a high continuous or alternating potential to the needle. Tilt the instrument by means of the leveling screws until the zero position remains the same with the voltage either on or off the needle. When this adjustment has been properly made, the position of maximum electrostatic capacity coincides with the natural zero of the instrument, and the mechanical and electrical zeros coincide. This adjustment is very important and should be checked whenever the instrument is used.

The connections used for bringing the mechanical and electrical zeros into coincidence is shown in Fig. 3. When this adjustment has been made the $a_0 V_0^2$ term of equation (18) is eliminated. This may be seen from a study of the values of the terms of the right hand side of equation (18).

alternating current[4] and measuring the power consumed in a load of known characteristics, but they are
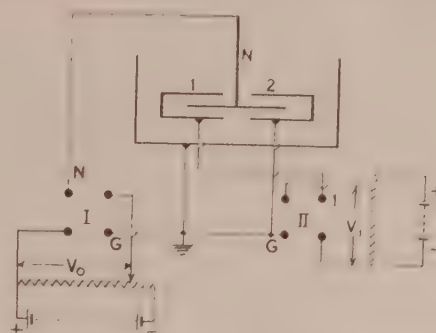
FIG. 4—QUADRANT CONNECTION FOR DETERMINING THE ELECTROMETER CONSTANTS

most readily determined with continuous current. The connections are shown in Fig. 4.

In the diagram of connections, V_2 is zero, V_1 is a relatively low potential and is very small compared to V_0, the needle voltage. Under these conditions, it is possible to neglect certain of the terms which form the left hand side of equation (19) and we may write

$$\theta [1 + R V_0^2] = a_1 V_1^2 + a_2 V_2^2 + b_1 V_0 V_1 + b_2 V_0 V_2 + c_0 V_0 \\ + c_1 V_1 + c_2 V_2 \qquad (20)$$

In Fig. 4 there are two reversing switches or com-

Value of terms of equation (18)

Position of Switch	$a_0 V_0^2$	$+a_1 V_1^2$	$+a_2 V_2^2$	$+b_1 V_0 V_1$	$+b_2 V_0 V_2$	$+c_0 V_0$	$+c_1 V_1$	$+c_2 V_2$	Deflection
Up	+	0	0	0	0	+	0	0	$= \alpha$
Down	+	0	0	0	0	−	0	0	$= \beta$

When this adjustment has been properly made $\alpha = \beta = 0$. Then if we take the sum of the two deflections, we will have

$$\alpha + \beta = 2 a_0 V_0^2 = 0$$

Therefore

$$a_0 = 0$$

It does not follow, however, that the $c_0 V_0$ term also equals zero when the mechanical and electrical zeros coincide. The constant, c_0, includes contact potentials, and when the quadrants are not connected and grounded, as in Fig. 3, these may become of importance. The contact, a_0, however, does not depend upon contact potentials, and it may be safely taken as zero when the electrometer is adjusted.

Neglecting the $a_0 V_0^2$ term, equation (18) reduces to

$$\theta [1 + R (V_0 - V_1)(V_0 - V_2) + S (V_1 - V_2)^2] \\ = a_1 V_1^2 + a_2 V_2^2 + b_1 V_0 V_1 + b_2 V_0 V_2 + c_0 V_0 \\ + c_1 V_1 + c_2 V_2 \qquad (19)$$

DETERMINATION OF THE CONSTANTS

In determining the constants, the quadrant connection is employed. In this connection the needle is at a high potential, one quadrant pair is connected to the case and grounded and the other is at a low potential. The constants may be determined by using

mutators marked with the Roman numerals I and II, respectively. There are four possible positions of the two commutators and the terms forming the right hand side of equation (20) have different signs depending upon the positions of the commutators. We obtain a deflection for each of the four positions of the commutators. The deflections and the signs or values of the corresponding terms are given below:

Position of Commutator I II		Value of Terms							Deflection
		$a_1 V_1^2$	$+a_2 V_2^2$	$+b_1 V_0 V_1$	$+b_2 V_0 V_2$	$+c_0 V_0$	$+c_1 V_1$	$+c_2 V_2 = [1 + R V_0^2]\theta$	
||	||	+	0	−	0	+	−	0 =["]	α
=	||	+	0	+	0	−	−	0 =["]	β
=	=	+	0	−	0	−	+	0 =["]	γ
|	=	+	0	+	0	+	+	0 =["]	δ

The constants are determined from the above deflections as follows:

$$[1 + R V_0^2](\alpha - \beta + \gamma - \delta) = -4 b_1 V_0 V_1 \qquad (21)$$

$$[1 + R V_0^2](\alpha - \beta - \gamma + \delta) = +4 c_0 V_0 \qquad (22)$$

$$[1 + R V_0^2](\alpha + \beta - \gamma - \delta) = -4 c_1 V_1 \qquad (23)$$

If we take readings of the deflections for two or more values of the voltages V_0 and V_1 we will obtain sufficient data to solve the above equations for the constants. For example, let α', β', γ' and δ' equal the deflections obtained when V_0' and V_1' are the voltages

applied to the needle and quadrant 1 respectively. Then from equation (21) we obtain

$$\frac{[1+R\ V_0'^2]}{b_1} = -\frac{4\ V_0'\ V_1'}{\alpha'-\beta'+\gamma'-\delta'} = X_1 \qquad (25)$$

For applied voltages V_0'' and V_1'' we get the deflections α'', β'', γ'' and δ'' for the four positions of the commutations respectively, and equation (26) follows:

$$\frac{[1+R\ V_0''^2]}{b_1} = -\frac{4\ V_0''\ V_1''}{\alpha''-\beta''+\gamma''-\delta''} = X_2 \qquad (26)$$

Here X_1 and X_2 are the numerical values of the right hand sides of equations (25) and (26) respectively.

Solving these two simultaneous equations for b_1 we find that:

$$b_1 = \frac{V_0'^2 - V_0''^2}{X_2\ V_0'^2 - X_1\ V_0''^2} \qquad (27)$$
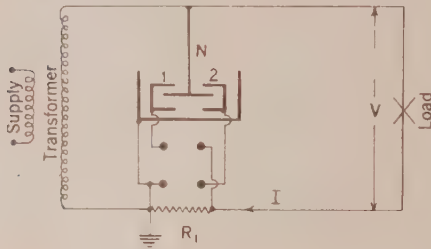
FIG. 5 –CONNECTIONS FOR MEASURING POWER WITH FULL VOLTAGE ON NEEDLE

and substituting the value of b_1 in equation (25) we obtain:

$$R = \frac{b_1\ X_1 - 1}{V_0'^2} \qquad (28)$$

In a similar manner we can obtain the other constants from equations (22), (23) and (24).

It is evident from the symmetrical construction of the electrometer that

$$a_2 = -a_1$$
$$b_1 = -b_2$$
$$c_1 = -c_2$$

We may also prove that:

$$a_2 = \tfrac{1}{2}b_1 \qquad (33)$$
$$a_1 = -\tfrac{1}{2}b_1$$

If we substitute these values of the constants in equation (19) it becomes

$$[1 + R\ (V_0 - V_1)\ (V_0 - V_2) + S\ (V_1^2 - V_2^2)\ ]\ \theta$$
$$= -\frac{b_1}{2}\ V_1^2 + \frac{b_1}{2}\ V_2^2 + b_4\ V_0\ V_1 - b_1\ V_0\ V_2 + c_0\ V_0$$
$$+ c_1\ V_1 + c_2\ V_2 \qquad (34)$$

If the quadrant electrometer is to be used in measuring power in alternating current circuits, it is only necessary to know the constants R and b_1. The other constants may either be reduced to zero or made negligible.

POWER MEASUREMENT

The quadrant connection is the one employed in measuring power in a-c. circuits. The quadrant electrometer may be connected so that there is either full voltage on the needle or only a fraction of the full voltage. A diagram of the connections for full voltage on the needle is shown in Fig. 5. The effective voltage across the load is V and the effective value of the load current is I. R_1 is a non-inductive capacity free resistance. Only one commutator is used.

When a-c. is applied to an electrometer, the needle potential and the quadrant potential are the instantaneous values of the applied voltages. The electrometer reads the integral of these applied voltages over a complete period. It is evident that this integral in the case of the c_0, c_1, and c_2 terms of equation (34) will equal zero because only the first power of the voltage is involved in these terms.

On alternating power measurements, V_1 and V_2, the quadrant potentials, are small compared to V_0, the needle potential and we may therefore neglect the S term, and as the c_0, c_1 and c_2 terms are equal to zero, we can write equation (19)

$$[1 + R\ V_0^2]\ \theta = -\frac{b_1}{2}\ V_1^2 + \frac{b_1}{2}\ V_2^2$$
$$+ b_1\ V_0\ V_1 - b_1\ V_0\ V_2 \qquad (35)$$

We will apply this equation to the measurement of the power consumed by the load of Fig. 5, keeping in mind the fact that V_0 is the instantaneous value of the potential from the needle to ground, and that V_1 and V_2 are the values of the instantaneous potentials from quadrant pairs No. 1 and No. 2 to ground respectively.

In Fig. 5, we see that

$$V_0 = v + i\ R_1$$
$$V_2 = i\ R_1\ or\ O$$
$$V_1 = O\ or\ i\ R_1$$

The values of V_1 and V_2 depend upon the position of the commutator.

The integral of the $b_1\ V_0\ V_1$ term over a complete period is as follows:

$$\frac{b_1}{T}\int_o^T V_0\ V_1 = \frac{b_1}{T}\int_o^T (v+i\ R_1)\ (i\ R_1)$$
$$= b_1\ (R_1\ I\ V \cos\Phi + I^2\ R_1^2)$$

There are two positions of the commutator and the value and signs of terms of equation (35) are given below. The circuit conditions and the applied voltage must remain constant while the deflections are measured.

Taking the algebraic sum of these deflections, we get

$$[1 + R\ V_0^2]\ (\beta - \alpha)$$
$$= -b_1\ I^2\ R_1^2 + 2\ b_1\ (R_1\ I\ V \cos\Phi + I^2\ R_1^2) \qquad (36)$$

The needle voltage V_0 is equal to the vector sum of the load voltage V, plus the drop across the non-inductive resistance R_1. Since the drop is very small com-

Position of Commutator	Value of Terms				Deflection
	$-\dfrac{b_1}{2}\,V_1^2$	$+\dfrac{b_1}{2}\,V_2^2$	$+b_1\,V_0\,V_1$	$-b_1\,V_0\,V_2$	
$\parallel$	0	$+\dfrac{b_1}{2}\,I^2\,R_1^2$	0	$-b_1(R_1\,I\,V\cos\Phi + I^2\,R_1^2)$	$= [1 + R\,V_0^2\,]\,\alpha$
$=$	$-\dfrac{b_1}{2}\,I^2\,R_1^2$	0	$+b_1(R_1\,I\,V\cos\Phi + I^2\,R_1^2)$		$= [1 + R\,V_0^2\,]\,\beta$

pared to the load voltage, we may assume that V_0 on the left hand side of equation (**36**) is equal to V.

Rewriting equation (**36**) and combining like terms we obtain

$$\frac{[1 + R\,V^2]\,(\beta - \alpha)}{2\,b_1\,R_1} = I\,V\cos\Phi + \frac{I^2\,R_1}{2} \qquad (37)$$

It is evident from equation (**37**) that the quadrant electrometer, with full voltage on the needle, measures the power consumed by the load plus one-half the power lost in the resistance R_1.

Equation (**37**) holds for all values of power factor, both leading and lagging. The only constants involved are b_1 and R which may be determined as already outlined.

If the quadrant electrometer is used to measure power with less than full voltage on the needle the diagram of connections are given in Fig. 6. Here V, I and R_1 have the same meanings as in Fig. 5. In this case the needle voltage equals the vector sum of the load voltage V plus the $I\,R_1$ drop divided by n, where n is the factor by which the voltage across the needle must be multiplied to give the total voltage of the circuit.

The instantaneous value of the voltage across the needle is

$$\frac{v + i\,R_1}{n}$$

There are two positions of the commutator and the value and the signs of the terms of equation (**35**) for reduced voltage on the needle are given below.

Taking the algebraic sum of these two deflections, we obtain
$$[1 + R\,V_0^2]\,\theta$$
$$= \frac{2\,b_1}{n}\,R_1\left(I\,V\cos\Phi + \frac{2-n}{2}\,I^2\,R_1\right) \qquad (41)$$

In practise, $I\,R_1$ is very small compared to V. It is usually less than one per cent of the load voltage and for practical purposes we may write
$$V_0 = \frac{V}{n}$$

We obtain, when we make this substitution in equation (**41**)

$$\frac{\left[1 + R\left(\dfrac{V}{n}\right)^2\right]}{2\,b_1} \cdot \frac{n}{R_1} \cdot \theta$$

$$= I\,V\cos\Phi + \frac{2-n}{2}\,I^2\,R_1 \qquad (42)$$

If n equals one, equation (**42**) reduces to equation
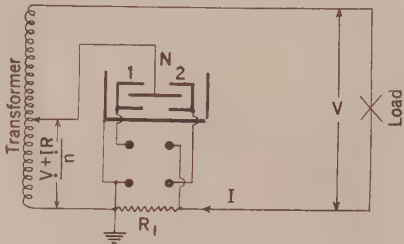
FIG. 6—MEASUREMENT OF POWER WITH LESS THAN FULL LINE VOLTAGE ON NEEDLE

(**37**), which is the power equation for full voltage on the needle of the quadrant electrometer. A further study of equation (**42**) shows that if n is equal to two, the last term of the equation vanishes; if n is greater, the last term becomes negative. This is true at all values of power factors. These deductions are verified by experiments reported in the experimental part of the paper.

Equation (**35**) gives the simplified form of the quadrant electrometer power relations. In this equation θ equals the algebraic sum of the two deflections α and β for the two positions of the commutator. The circuit conditions and the applied voltage are assumed to remain constant while these readings are being taken. Under these conditions we noted that

$$V_1 = I\,R_1 \text{ or } 0$$

and

$$V_2 = 0 \text{ or } I\,R_1$$

Position of Commutator	Value of Terms				Deflection
	$-\dfrac{b_1}{2}\,V_1^2$	$+\dfrac{b_1}{2}\,V_2^2$	$+b_1\,V_0\,V_1$	$-b_1\,V_0\,V_2$	
$\parallel$	0	$+\dfrac{b_1}{2}\,I^2\,R_1^2$	0	$-b_1\left(\dfrac{R_1\,I\,V\cos\Phi + I^2\,R_1^2}{n}\right)$	$= [I + R\,V_0^2]\,\alpha$
$=$	$-\dfrac{B_1}{2}\,I^2\,R_1^2$	0	$+b_1\left(\dfrac{R_1\,I\,V\cos\Phi + I^2\,R_1^2}{n}\right)$	0	$= [\ + R\,V_0^2]\,\beta$

Therefore, if we determine the signs and the values of the terms of equation (**35**) for the two commutator positions and take their algebraic sum, we may write

$$[1 + R\,V_0{}^2]\,\theta = 2\,b_1\,V_0\,V_1 - b_1\,V_1{}^2 \qquad (44)$$

This equation is a simplified form of equation (**35**). If we substitute in equation (**44**) the values of the needle voltage to ground, V_0, and the drop across the resistances, V_1, expressed in the form of their vector relations, we obtain exactly the same result as was found by the method used in determining equations (**37**) and (**41**).

Errors

The sources of error in the measurement of power with the quadrant electrometer have already been ably discussed in an Institute paper[5].

II—Experimental

Determination of the Constants b_1 and R. The constants b_1 and R are best determined with continuous potentials, although they may be determined with alternating potentials.

The diagram of connections is given in Fig. 4. The voltage applied to the needle could be varied through a range of from about 50 to 600 volts. It was measured with a Weston Laboratory Standard Voltmeter. The voltage applied to the quadrants was varied from 2 to 15 volts and was measured with a Siemens and Halske instrument.

The quadrant electrometer was set up, leveled, and carefully adjusted, with about 600 volts on its needle, until its electrical and mechanical zeros coincided. Then readings of the deflections for the different positions of the two commutators were taken for various values of V_0 and V_1. Four readings were taken for each set of voltages, which were maintained constant while the deflections were noted. In taking a set of readings it is best to commutate in a regular manner and read at regular intervals after commutating.

The electrometer used was one constructed in the electrical laboratories of the Johns Hopkins University. The quadrants were of aluminum. The inside diameter of the cylindrical box from which they were cut was 15.24 cm. and its height was 3.81 cm. The needle was also of aluminum, and the length of its phosphor-bronze suspension was approximately 20 cm. The quadrant pairs and the needle were insulated by special bakelite supports.

The readings upon which the calculations of the constant b_1 and R are based are given in Table I.

The first three sets of readings were taken with V_0 equal to 100 volts and they give an average X_1 of 143.73. The next two sets of readings are for V_0 equal to 270 volts, and X_2 equals 143.0. The last two sets of readings were at 500 volts and X_3 average equals 137.0.

Calculating b_1 from these results in accordance with equation (**27**) we get an average b_1 of

$$b_1 = + 0.00695$$

calculating R from equation (**28**) gives

$$R = - 1.95 \times 10^{-7}$$

Proof of the Power Equation with Full Voltage on Needle. Equation (**37**) states that the deflection of a quadrant electrometer is proportional to the power consumed in the load plus one-half the power loss in the shunt resistance R_1 at any value of the power factor.

TABLE I

V_0 Volts	V_1 Volts	Position of Commutator No. I	No. II	cm.	cm. $\theta =$ $\alpha - \beta - \gamma - \delta$	$-\dfrac{4\,V_0\,V_1}{\theta}$
100	5	‖	‖	− 3.6 = α		
		=	‖	+3.35 = β		
		=	=	−3.6 = γ		
		‖	=	+3.35 = δ		
					−13.9	+143.9
100	10	‖	‖	− 7.35		
		=	‖	+ 6.52		
		=	=	− 7.32		
			=	+ 6.55		
					−27.74	+144.1
100	15	‖	‖	−11.3		
		=	‖	+ 9.65		
		=	=	−11.3		
		‖	=	+ 9.65		
					−41.9	+143.2
270	5	‖	‖	− 9.6		
		=	‖	+ 9.3		
		=	=	− 9.6		
		‖	=	+ 9.3		
					−37.8	+142.5
270	10	‖	‖	−19.6		
		=	‖	+18.35		
		=	=	−19.6		
		‖	=	+18.35		
					−75.9	+143.5
500	2	‖	‖	− 7.12		
		=	‖	+ 7.55		
		=	=	− 7.1		
		‖	=	+ 7.5		
					−29.27	+136.6
500	5	‖	‖	−18.3		
		=	‖	+18.15		
		=	=	−18.25		
		‖	=	+18.15		
					−72.85	+137.4

In order to check this relation the quadrant electrometer was connected up as in Fig. 9, and three loads were used in turn. The first load was a non-inductive resistance R_0. The second load consisted of an inductance, L, and the third, of a mica condenser, C.

The test at unity power-factor load will be considered first. In this test, the secondary voltage of the transformer was maintained constant at 100 volts and 60 cycles. Readings of the deflections were taken with three values of R_1, namely, 100, 2000 and 7000 ohms respectively. The value of the load resistance, R_0, was adjusted for each value of R_1 so that the power loss in R_0 was maintained constant at 0.32 watts.

The constant of the electrometer with 100 volts applied to the needle is

$$K = \frac{1 + R\,V^2}{2\,b_1} = \frac{(1 - 1.95 \times 10^{-7} \times 100^2)}{2 \times 0.00695} = 71.8$$

The results of the unity power factor test are given in Table IV.

TABLE IV

R_0 Ohms	R_1 Ohms	I Milli-Ampere	$I^2 R_0$ Load Watts	$\frac{I^2 R_1}{2}$ Watts	θ cm.	Electrometer $\frac{K\theta}{R_1}$ Watts	$I^2 R_0 + \frac{I^2 R_1}{2}$ Watts calculated
29250	1000	3.31	0.32	0.006	4.5	0.324	0.326
27125	2000	3.44	0.32	0.013	9.45	0.339	0.333
13650	7000	4.83	0.32	0.082	39.6	0.406	0.402

In Table IV, the current, I, is calculated from the known constants of the circuit. The watts consumed in the load, $I^2 R_0$, and one-half the loss in the shunt resistance R_1 are also calculated, as are the values given in the last column.

A comparison of the watts registered by the electrometer for the different values of R_1 and the watts calculated, as given in the last column of Table IV, shows a fairly close agreement. A comparison of the last two columns of Table IV show conclusively that at unity power factor equation (37) holds and the instruments read the watts lost in the load plus one-half the loss in the resistance shunting the quadrants.

The inductive load, lagging power factor test followed the resistance test. The inductance used as the load consisted of an air-cored copper coil with a resistance of 1650 ohms and a coefficient of self-induction of 7.73 henries. At a frequency of 60 cycles the reactance was 2915 ohms. Readings were taken at two values of R_1 and the applied voltage was adjusted so as to maintain the current constant and thus keep the load at a uniform amount.

TABLE V

Voltage	R_1 Ohms	Circuit Impedance Ohms	I Milli-amp.	Load Watts	$\frac{I^2 R_1}{2}$ Watts	θ cm.	Electrometer $\frac{K\theta}{R_1}$ Watts	Load $+\frac{I^2 R_1}{2}$ Watts Calculated
46.5	1000	4664	1.178	0.23	0.069	4.1	0.296	0.299
55.0	2000	3940	1.178	0.23	0.138	10.2	0.367	0.368

The voltages used were 55 and 46.5 volts respectively and at this value of the voltage the constant of the electrometer = 72.

The results are given in Table V. In this test the power factor was 56.6 per cent lagging.

A comparison of the watts as measured by the quadrant electrometer with the calculated watts shows a good agreement. A study of the last two columns

of Table V shows conclusively that, at a lagging power factor of 56.6 per cent, the electrometer reads the power consumed by the load plus one-half the power lost in the shunt resistance.

The capacity load test was made with a standard mica condenser whose capacity was 1/10 of a microfarad. The frequency used was 60 cycles. Readings were taken at three values of the shunt resistance R_1 and the applied voltage was varied between the limits of 396 and 400 volts so as to maintain the current through the circuit and the load constant. At 400 volts the constant of the electrometer is 69.7. The results are given in Table VI.

TABLE VI

Voltage	R_1 Ohms	Circuit Impedance Ohms	I Milli-amp.	Load Watts	$\frac{I^2 R_1}{2}$ Watts	θ cm.	Electrometer $\frac{K\theta}{R_1}$ Watts	Load $\frac{I^2 R_1}{2}$ Watts
396	1000	26520	14.9	0.027	0.111	1.95	0.136	0.138
398	2000	26570	14.9	0.027	0.222	7.15	0.249	0.249
400	4000	26800	14.9	0.027	0.444	27.10	0.472	0.471

The watts consumed by the load are determined by subtracting from the watts measured by the electrometer one-half of the loss in the shunt resistance R_1. Another method of determining the watts load is to plot the watts measured by the electrometer as ordinates against the values of the shunt resistance R_1 as abcissas. These points should lie on a straight line, as shown in Fig. 10. If this line is extended to the ordinate axis it will cut that axis at a value equal to watts lost in the load. From Fig. 10 we see that the load loss is equal to 0.027 watts. The power factor of
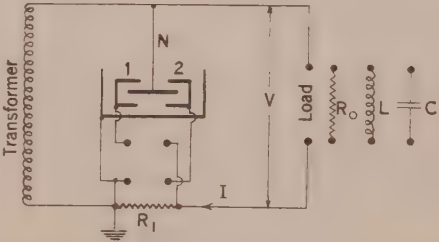
FIG. 9—QUADRANT ELECTROMETER WITH FULL VOLTAGE ON NEEDLE AND DIFFERENT LOADS

the condenser load used in this test is 0.47 per cent.

A comparison of the results given in the last two columns of Table VI show clearly that the quadrant electrometer with full voltage on the needle reads the loss in the load plus one-half the loss in the shunt resistance R_1. The curve plotted from the results in Fig. 10 also confirms this conclusion.

The results of these three tests prove conclusively the correctness of equation (37); namely, that the quadrant electrometer with full voltage on the needle reads the power consumed by the load plus one-half the loss in

the shunt resistance, irrespective of the value of the power factor.

Proof of the Power Equation with Reduced Voltage on the Needle. Equation (**42**) applies to this type of measurement. The sign of the last term, or correction term, depends upon the value of n. If n is equal to two the term vanishes. If n is greater than two the term becomes negative. In order to check this relation readings were taken at unity power factor load for n

Fig. 10—Curve Showing the Relation Between Watts Measured by the Electrometer and the Shunt Resistance, R_1 with Full Voltage on the Needle. Plotted from the Results of Table VI

equal to three different values. The connections used are those given in Fig. 6.

The first test was run with n equal to two and the voltage of the transformer was 160 volts at 60 cycles. The voltage applied to the electrometer needle was one-half of the transformer voltage and equaled 80 volts. The constant of the electrometer for this needle voltage was 71.9.

Readings were taken at three values of the shunt resistance, and the load which consisted of a non-inductive resistance was maintained constant. The results are given in Table VII.

It is apparent from the results given in Table VII

TABLE VII

R_0 Ohms	R_1 Ohms	I Milli-amp.	$I^2 R_0$ Load Watts	Electrometer	
				θ cm.	$\dfrac{n K \theta}{R_1}$ Watts
29250	1000	5.29	0.825	5.75	0.826
27125	2000	5.49	0.825	11.5	0.826
20000	5000	6.4	0.82	28.7	0.825

that when n equals two the quadrant electrometer reads directly the power consumed in the load, and the correction term vanishes.

The second unity power-factor test was made with one-third of the transformer voltage applied to the needle, that is n equaled three. The transformer voltage in this test was 240 volts at 60 cycles and this

gave a needle voltage of 80, the same as used in the run with n equal to two. The electrometer constant equaled 71.9 in this test also.

For the value of n equal to three, the correction of equation (**42**) becomes negative and equals

$$-\frac{I^2 R_1}{2}$$

The results of this test are given in Table VIII. Readings were taken for three different values of shunt resistance R_1.

It is evident from the results given in Table VIII that

TABLE VIII

R_0 Ohms	R_1 Ohms	I Milli-amp.	$I^2 R_0$ Load Watts	$\dfrac{I^2 R_1}{2}$ Watts	Electrometer		$\dfrac{I^2 R_0 - I^2 R_1}{2}$ Watts Calcu-lated
					θ cm.	$\dfrac{n K \theta}{R_1}$ Watts	
29250	1000	7.93	1.84	0.032	8.45	1.82	1.81
27125	2000	8.24	1.84	0.068	16.2	1.75	1.77
13650	7000	11.62	1.84	0.473	44.2	1.36	1.37

when n is equal to three the correction term becomes negative. The check between the calculated watts and the watts as measured by the electrometer is good.

The third unity power-factor test was made with n equal to four. Under this condition equation (**42**) becomes

$$\frac{\left[1 + R\left(\dfrac{V}{n}\right)^2\right]}{2 b_1} \frac{n}{R_1} \theta = I V \cos \Phi - I^2 R_1$$

Readings were taken for three conditions. In the first, the loss in the shunt resistance was less than the load. In the second, the loss in the load and the loss in the shunt resistance were equal and in the third the loss in the shunt resistance was greater than the loss in the load. This last condition should give a negative deflection of the electrometer.

The voltage of the transformer was 400 volts at 60 cycles. This gives, with n equal to four, a needle voltage of 50 volts and an electrometer constant of 72. The results are given in Table IX, which is divided into two parts. Part I gives the calculated watts and Part II gives the electrometer readings.

A study of Table IX shows that the electrometer reading reversed and became negative when the loss in the shunt resistance was greater than the load loss as predicted. A comparison of Parts I and II shows clearly that the experimental results check the theory.

The experimental results of Tables VII, VIII and IX definitely prove that the sign of the correction term of equation (**42**) depends upon the value of n and not upon the value of the power factor.

In order to prove that equation (**42**) holds at low power factor, a set of results is given in Table X, that were taken on another electrometer which was convenient. The load consisted of a high voltage con-

denser of about 0.02 microfarads capacity. The voltage applied was 7500 volts at 60 cycles. The value of n was six and the electrometer constant was 83.5. The current was measured by another electrometer which was used as a voltmeter.

TABLE IX

Part 1

R_0 Ohms	R_1 Ohms	I Milli-Amp.	$I^2 R_0$ Load Watts	$I^2 R_1$ Watts	$I^2 R_0 - I^2 R_1$ Watts Calculated
15000	10000	8.	0.96	0.64	+0.32
10000	10000	10.	1.0	1.0	0
10000	15000	8.	0.64	0.96	−0.32

Part 2

R_0 Ohms	R_1 Ohms	Electrometer			
		Position of Com-mutator	Readings cm.	Deflection cm.	$\dfrac{n K \theta}{R_1}$ Watts
15000	10000	‖	+6.2	+11.5	+0.33
		=	−5.3		
10000	10000	‖	−0.7	0	0
		=	−0.7		
10000	15000	‖	−7.15	−16.25	−0.312
		=	+9.1		

For n equal to six the correction term becomes $-2 I^2 R_1$.

The watts measured by the electrometer are plotted against R_1 in Fig. 11. The readings lie on a straight line and the intercept of this line on the Y axis gives a loss in the condenser under test of 0.264 watts. A

TABLE X

R_1 Ohms	I Milli-ampere	Load Watts	$2 I^2 R_1$ Watts	Electrometer		Load $-2 I^2 R_1$ Watts Calcu-lated
				θ cm.	$\dfrac{n K \theta}{R_1}$ Watts	
2000	4.7	0.264	0.085	+0.7	+0.175	+0.179
4000	4.7	0.264	0.177	+0.7	+0.0875	+0.087
5000	4.7	0.264	0.221	+0.4	+0.040	+0.043
8000	4.7	0.264	0.354	−1.45	−0.09	−0.09
10000	4.7	0.264	0.442	−3.55	−0.178	−0.178

comparison of the last two columns of Table X shows an excellent agreement between the watts as measured by the electrometer and the calculated watts. The power factor of the load used in this test was 0.75 per cent. The results in Table X also show that the electrometer deflection changed to negative when the loss $2 I_2 R_1$ became greater than the load.

The results of this test prove that equation (42) holds at low power factor.

The experimental results prove conclusively that equations (37) and (42) are derived correctly and that they are applicable at all values of power factor.

CONCLUSION

In order to use the quadrant electrometer for the measurement of power, it is necessary only to determine two constants, namely b_1 and R. This may be

done with continuous current. In some instruments, R has a negligible or zero value.

The quadrant electrometer may be used in measuring a-c. power with either full or a fraction of the full voltage applied to its needle. In the case where full voltage is used on the needle, equation (37) holds, and
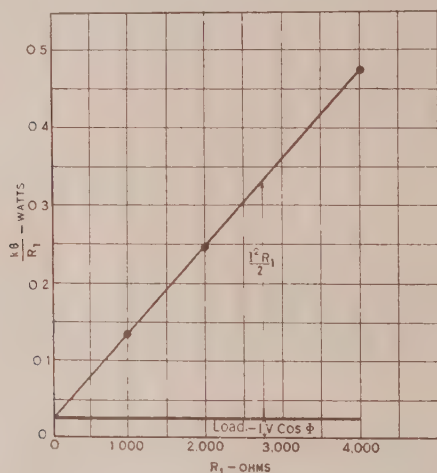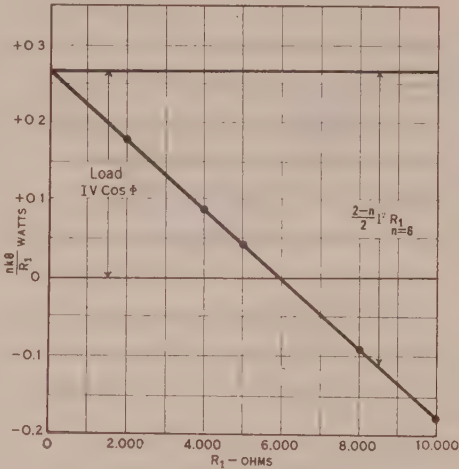

FIG. 11—CURVE SHOWING THE RELATION BETWEEN WATTS MEASURED BY THE ELECTROMETER AND THE SHUNT RESISTANCE R_1 WITH $n = 6$. PLOTTED FROM THE RESULTS OF TABLE X

where a fractional part of the full voltage is applied to the needle, equation (42) holds. These equations hold for all values of the power factor both lagging and leading.

The general power equation of the quadrant electrometer for a-c. circuits is given by equation (44). Where V_0, the voltage applied to the needle, and V_1, the voltage applied to the quadrant pairs, are to be expressed in their vector form. By means of equation (44) it is a simple matter to determine what the instrument will read under any conditions in an alternating current circuit.

The experimental data presented amply proves the theory given in this paper.

The author wishes to thank Mr. W. W. Hill and Mr. G. A. Irland for their assistance in the experimental work.

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Notes on the Development of a New Type of Hornless Loud Speaker

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Synopsis.—The paper describes a series of tests directed to the evolution of a loud speaker, free from resonance. Various types of sound source were tried. For the most part horns were avoided. Diaphragms, when employed, were either so light and stiff that their natural resonance was above the essential frequency range, or so flexible that their resonance was below the lowest important acoustic frequency. Best results were obtained with the latter type, and it is shown on theoretical grounds that a small diaphragm, the motion of which is controlled by inertia only, and located in an opening in a large flat wall, will give an output sound pressure proportional to the actuating force, independent of frequency. It should be possible to make an ideal sound reproducer on this principle. A practical loud speaker which approximately fulfills the above conditions has now been evolved. It consists of a flexibly-supported paper cone actuated by a coil in a magnetic field and provided with a baffle. As compared with ordinary loud speakers, this instrument radiates much more of the low tones and more of the very high frequencies which makes for clearer articulation.

The extension of the range of response of the loud speaker to higher and lower frequencies, makes defects in the remainder of the system more noticeable, particularly roughness and blasting due to overworked amplifiers. It is, therefore, important that the amplifier used with the new loud speaker be designed to have ample capacity.

* * * * *

INITIAL TESTS WITH NON-RESONANT TYPES

SEVERAL years ago tests were undertaken in the Research Laboratory of the General Electric Company, to ascertain whether or not it would be possible, by sacrificing sensitivity, if necessary, to produce a loud speaker free from the most objectionable of the distortion which characterizes loud speakers in general.[2]

Happily in the later designs it was found that the anticipated sacrifice of sensitivity was not necessary.

The worst distortion in the ordinary loud speaker is due to horn-resonance and diaphragm-resonance. To eliminate the horn-resonance, it was proposed to abandon the horn. To avoid the diaphragm-resonance we might, for example, eliminate the diaphragm, by using a "talking arc;" or we might use diaphragms in which the resonance frequencies were above or below the working range.

One of the first undertakings was to build a resistance-capacity-coupled amplifier[3] in which the final stage was a tube having an oscillator rating of 250-watts output. With a 1500-volt plate supply, this amplifier could deliver about 70 milliamperes of sine wave current at 200 volts, with practically no wave-form distortion, and it was possible to test some very insensitive devices. Among the things tried were:

1. A gold leaf thermophone with an area of about one-half square foot, shown in Fig. 1. The voice current superimposed on a direct current causes temperature fluctuations in the gold leaf. The adjacent air expands and contracts and produces sound waves.

2. Various designs of electrostatic loud speakers with large diaphragms: In these the diaphragm is a thin sheet of conducting material, actuated by the electrostatic attraction between it and an electrode placed close to it.

3. A siren, shown in Fig. 1: Instead of moving a
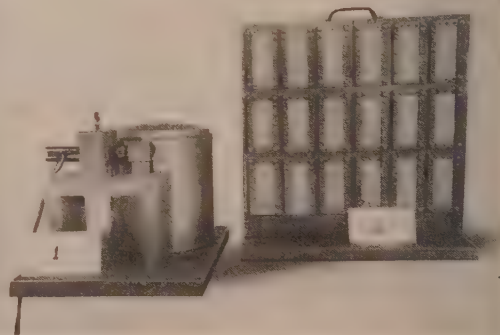
FIG. 1—SIREN AND GOLD-LEAF THERMO-PHONE

diaphragm to set up air waves, the voice currents are made to operate a delicate throttle-valve which controlled the amount of air issuing from a jet. This principle is employed in the "Creed Stentorphone" evolved by Mr. Gaydon and manufactured by Mr. Creed of Croyden, England.

4. An agate cylinder machine, depending on varying the frictional force between a rotating drum of polished agate and a piece of metal attached to the diaphragm: This principle was first applied by Edison[4] using chalk cylinders, and later by Johnson and Rahbeck who used agate.[5] A modified form of frictional machine,

1. Both of the Research Laboratory of the General Electric Co.

2. A general discussion in the form of a symposium on the loud speaker problem is published in *Proceedings* of the Physical Society of London, Vol. 36, Parts 2 and 3, Feb. & Mar., 1924.

3. The amplifier was used in conjunction with a special high grade transmitter. The construction and calibration of condenser transmitters are described by F. C. Wente in the *Physical Review*, July, 1917, and May, 1922. The theory of air damping as applied to the condenser transmitter is discussed by I. B. Crandall, *Phys. Rev.*, June, 1918.

Abridgment of paper presented at the Spring Convention of the A. I. E. E., St. Louis, April 13-17, 1925. Complete copies to members on request.

4. British patent No. 2909,—1877.

5. Described in *Zeitschrift fur Technische Physik*, 1921, No. 11, also *Journal* I. E. E., No. 61, July 1923, p. 713.

called the "Frenophone," has recently appeared.[6]

5. A talking arc.

6. Multiple unit area devices, made up of a large number of similar magnetic telephones, placed close together in a panel.

7. Combinations of several horn instruments, having different characteristics, so that each supplements the others. Fig. 2 shows a photograph of this arrangement.

8. The induction phone developed by Dr. C. W. Hewlett.[7]
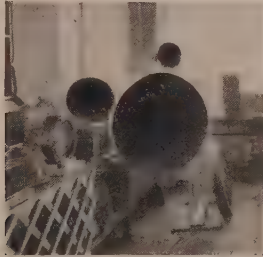
FIG. 2—TRIPLE-HORN LOUD SPEAKER

This is illustrated in Fig. 3. The diaphragm is a thin sheet of aluminum loosely supported between two pancake-type coils, wound with suitable venting spaces. Direct current is passed through the coils in such a direction as to give a radial field in the region of the diaphragm, and the voice current circuit is connected so that both coils act as primaries to induce currents in the diaphragms. The resulting force can be made to be almost uniform over the whole diaphragm.

9. Various designs of small diaphragm moving coil instruments.
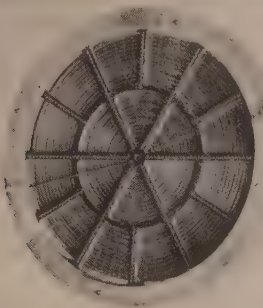
FIG. 3—HEWLETT INDUCTION TYPE LOUD SPEAKER

Fig. 6 shows a number of instruments set up for comparison.

Of the possibilities, some were dropped after one or two experiments, while the more promising types were

6. Model exhibited at Liverpool meeting of British Association for the Advancement of Science, Sept. 1923. See *Sci. American*, Jan. 1924.

7. *Phy. Rev.*, 17, p. 257, 1921. *Phy. Rev.*, 19, p. 52, 1922. *Jour. Opt. Soc. Am.* 4, p. 1059, 1922.

the subjects of considerable development. The electrostatic phone is capable of giving very fine quality reproduction, but owing to the low breakdown strength of air, only a small force can be applied to the diaphragm and a very large area is required to give a reasonable volume of sound.

TEST OF SMALL INERTIA DIAPHRAGM

One of the chief difficulties encountered with most of the types of loud speaker tested, was to obtain adequate radiation of low tones. Mr. Kellogg suggested using a coil-driven diaphragm with practically no elastic restoring force, so that at low frequencies, very large amplitudes could be attained. In an ordinary telephone the stiffness of the diaphragm is depended upon to prevent its sticking to the magnet poles and is, therefore, not suitable where an entire lack of restoring force is desired. On the other hand, the moving coil drive, is eminently suited to this purpose, since no stabilizing force is required. Fig. 4 shows the construction of the first model built to try out the free diaphragm principle.
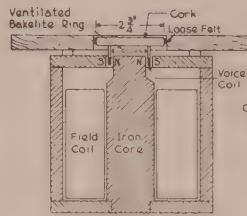
FIG. 4—FIRST MODEL OF INERTIA CONTROLLED DIAPHRAGM LOUD SPEAKER   FIG. 5—IMPROVED DESIGN OF INERTIA DIAPHRAGM, LOUD SPEAKER
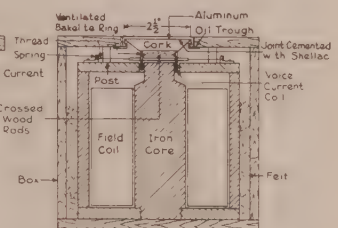
Not only did this device produce more of the low tones than any previously tried, but it held up remarkably well for the very high notes, not showing any marked resonance. It did, however, have a rough quality in voice reproduction, which was corrected in the later designs.

TRIAL OF TRIPLE HORN LOUD SPEAKER

The multiple unit horn device, already mentioned and shown in Fig. 2, was first suggested and worked on in our group by Mr. Kellogg. It was an attractive possibility, especially in view of the sensitivity obtainable with horns, and the ease with which the balance between high and low tones could be adjusted. For the lower end of the scale, a Baldwin phone with a large exponential horn seemed to be the best combination of available apparatus, while some higher pitched phones with smaller horns took care of the middle and upper ranges. Experiments with this arrangement showed clearly that the three instruments supplemented each other, the combination sounding much better than any one alone, and the consciousness on the part of the listener of the presence of a horn was much less pronounced than in the case of a single horn device. But

the Baldwin phone would not give a sufficient low frequency output and after a number of attempts to build a suitable low-pitched phone, the conclusion was reached that the most satisfactory low-pitched phone would be one designed along the lines of the moving coil instrument already described. However, when this construction was adopted, no supplementary high pitched instruments were needed.

IMPROVED DESIGNS OF INERTIA DIAPHRAGM INSTRUMENTS

Fig. 5 shows the manner of construction of a moving coil instrument designed with a view to avoiding two of the possible causes of the rough quality which had characterized the machine shown in Fig. 4, namely, friction around the edges, and failure of the diaphragm to act as a true piston, or remain flat during vibrations. A maximum of rigidity, combined with light weight, was sought in the diaphragm design, an oil seal was provided around the edge, and the support consisted of four threads at right angles, held in slight tension, so that motion was very free in the axial direction, but practically no sidewise movements could take place. Vibration amplitudes as great as 1/32 inch were frequently observed on this diaphragm. The rough quality was practically eliminated in the new design. Provision was made for boxing in the instrument, and an interesting experience in this connection was that of placing the box over the back which had the same general effect on sound quality as applying a short horn to the front of the diaphragm. Both helped to bring out the low tones and gave rise to some resonant effects. Bringing out the low tones was due principally to preventing circulation of air between the front and back of the diaphragm. The resonance was in the horn in one case, and in the box in the other. A peculiarity of devices employing very flexibly supported diaphragms is that resonant air chambers behind the diaphragm do about as much harm as resonant cavities in front of the diaphragm, the diaphragm usually taking part in the resonance. Attempts to damp the interior of the box with felt were not entirely successful.

THE USE OF A BAFFLE

A happy solution of the problem of preventing circulation was obtained by employing a flat baffle-board, at the suggestion of Mr. Rice, who was the first of the group to recognize the importance of the circulation factor in preventing the radiation of low tones. With the flat baffle, no air resonance occurs and both sides of the diaphragm give useful radiation, the total power radiated for a given diaphragm amplitude being nearly four times as great as that radiated when the back of the diaphragm is enclosed.

DEFINITION OF TERM "INERTIA CONTROLLED"

Subsequent experiments were devoted largely to the development of the free diaphragm type of sound reproducer, in which throughout the essential frequency range the electrical driving force is expended in accelerating the mass of the diaphragm. We shall speak of such diaphragms as "inertia controlled." A certain amount of elastic restoring force is unavoidable in the supporting system, and consequently the diaphragm must have a natural frequency. But if the natural frequency is below the important acoustic frequency range, the diaphragm may properly be described as inertia controlled. We have obtained best results with natural frequencies below about 70 cycles per second. Higher natural frequencies can be tolerated if the vibrations are well damped.

THEORY FOR LARGE AND SMALL DIAPHRAGMS

Diaphragms may be classified according to their mechanical properties as:

1. Interia controlled
2. Damped or resistance controlled
3. Elastic controlled
4. Resonant
5. Diaphragms having wave action or phase differences between the different parts of the surface.

Of these, the first three have simple relations between actuating force, frequency, and amplitude of motion, and would, therefore, appear to offer most promise of affording a sound source of constant efficiency. The resistance-controlled diaphragm, while difficult to obtain, is included in the list as representing a possible type and is of theoretical interest. It will be assumed in discussing the first three types of diaphragm that all parts of the surface move together, which means that either the diaphragm is small and rigid, or else the actuating force is applied to all parts. The wave action diaphragm is best represented by the large shallow paper cones which have been employed with considerable success. Familiar examples of this type are found in the Pathé and new Western Electric 540 AW loud speakers. Some other experiments along these lines were recently reported by Sutton.[8] Here the actuating force is applied at the center, or vertex, and flexural waves radiate toward the outer edge. If there is considerable energy loss so that these waves are attenuated rapidly, the net result is that at high frequencies a small area of the diaphragm near the vertex radiates sound, while at lower frequencies a larger area works. If the attenuation of the flexural waves is small, standing-wave conditions exist and there is a series of frequencies at which resonance occurs.

The relation between amplitude, frequency, and driving force, for diaphragms with pure elastic, resistance, or inertia control is as follows. Assume that the diaphragm vibrates with simple harmonic motion at a frequency, f cycles per second, and with an amplitude X centimeters, under the action of a driving force which alternates between $+ F$ and $- F$ dynes.

8. *Wireless World and Radio Review*, Nov. 19, 1924.

With elastic control, if K is the diaphragm stiffness in dynes per centimeter,

$$X = \frac{F}{K} \tag{1}$$

or, the amplitude is proportional to the maximum of the alternating force, independent of frequency.

With resistance control of motion, if R is the resistance to motion in dynes per unit velocity,

$$X = \frac{F}{2 \pi f R} \tag{2}$$

or, the amplitude is proportional to the applied force divided by the frequency.

In the case of inertia control if the diaphragm mass is M grams,

$$X = \frac{F}{\omega^2 M} = \frac{F}{4 \pi^2 f^2 M} \tag{3}$$

or the amplitude for a given driving force varies inversely as the square of the frequency.

There are two classes of diaphragms the sound radiation of which are simple functions of amplitude, frequency and diaphragm size.

a.   Diaphragms large enough in comparison with the longest waves to give plane-wave radiation for all essential frequencies.

b.   Diaphragms small enough in comparison with the shortest waves, to be treated as virtually point sources for all essential frequencies, circulation of air between the front and back of the diaphragm being prevented either by a baffle or by enclosing the space on one side of the diaphragm.

The power in ergs per second[9], radiated from one side of the large diaphragm is

$$P = \frac{1}{2} \rho v S \omega^2 X^2 \tag{4}$$

in which

ρ = mean density of air in grams per c. c.

v = velocity of sound in air in cms. per sec.

S = area of diaphragm in sq. cm.

$\omega = 2 \pi f$.

X = amplitude of diaphragm motion, assumed to be the same over the entire surface.

In the case of the small diaphragm, the power radiated from one side is[10]

$$P = \rho \frac{S^2 \omega^4 X^2}{2 \beta v} \tag{5}$$

in which β is the solid angle into which the radiation takes place, 4π for complete spherical waves, and 2π for hemispherical waves, or in other words, if a flat

baffle is used.   With a flat baffle, the radiation from both sides of the diaphragm is

$$P' = \rho \frac{S^2 \omega^4 X^2}{2 \pi v} \tag{6}$$

For these two types of diaphragms we can see from equations (4) and (5) what would have to be the relation between amplitude and frequency in order to have the sound output the same at all frequencies.

For the large diaphragm, equation (4) shows that P becomes independent of ω or of f if X varies as $\frac{1}{f}$, and equation (2) shows that applying a force, F, the same at all frequencies to a resistance controlled diaphragm, gives an amplitude which varies as $\frac{1}{f}$

Turning to the case of the small diaphragm working with a baffle, equation (6) shows that for constant sound output $X^2 \omega^4$ must be constant, or the amplitude must vary inversely as the square of the frequency, and equation (3) shows that a constant driving force and inertia controlled motion gives just this required relation between frequency and amplitude.   This relationship was pointed out by Kellogg who took especial interest in this type of device and designed all of the models employing small rigid diaphragms.   The driving force independent of frequency is available in the form of a coil in a constant magnetic field and with enough resistance in the circuit compared with the reactance to make the current independent of frequency.

Effect of Intermediate Diaphragm Size

Formulas for the sound radiation from a flat circular diaphragm situated in a flat wall or baffle of infinite extent have been developed by Rayleigh[11], all parts of the diaphragm being assumed to have the same motion. Fig. 6 shows the relative output at different frequencies of an inertia controlled diaphragm six inches in diameter, actuated by a vibratory force of variable frequency but constant magnitude.   For wave lengths greater than about 1.5 feet, (46 cm.), the diaphragm may be treated as a small source, and the sound output is constant.   At frequencies for which the wave length is less than the diameter of the diaphragm, the radiation practically follows the law expressed in equation (4) for large area diaphragms.   Within this part of the frequency range inertia control gives too rapid a drop in amplitude as the frequency is increased, with the result that the power radiated is less at high frequency. There is, however, a compensating effect.   At the same time that the total radiation becomes less, the directivity increases, and the listener in front of the diaphragm receives a larger share of the total power radiated.   The result is that with a diaphragm of this size, the listener, if stationed in front of the diaphragm, loses very little

9.   Rayleigh, Theory of Sound.   Vol. II.   Page 16.
10.   Rayleigh, Theory of Sound.   Vol. II.   Page 113.

11.   Theory of Sound.   Vol. II.   Pages 162-165.

of the high frequency components. Even with larger diaphragms, very pleasing results have been obtained with inertia-controlled diaphragms, notably the Hewlett induction phone in which a 24-in. diaphragm has been employed with good effect. The directive properties of this large area diaphragm are very striking.
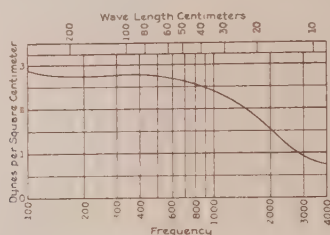
FIG. 6—RADIATION CHARACTERISTICS OF INERTIA CONTROLLED DIAPHRAGM SIX IN. (15 CM.) IN DIAMETER

Ordinates are R. m. s. Pressure at One Meter

$$\text{Distance} = \sqrt{\rho v \times \frac{\text{Power radiated from one side}}{\text{Area of hemisphere of 100 cm. radius}}}$$

In which

ρ = Density of Air
= 0.0012 grams per cc.
v = Velocity of Sound
= 3.42 × 10^4 cm. per sec.
Actuating force assumed = 83.000 dynes = r. m. s. value
Mass = 10 grams

In order to radiate in accordance with equation (6) or as a small source, up to 5000 cycles, a diaphragm would have to be less than about $1\frac{1}{2}$ inches in diameter, but since experiments indicate that much larger inertia-controlled diaphragms give good results, there is no justification for limiting the size to the value mentioned, particularly as sensitivity is gained from the adoption of larger sizes.

REQUIREMENTS FOR TRUE PISTON ACTION

Since the inertia-controlled small diaphragm appeared, from both theoretical and experimental evi-
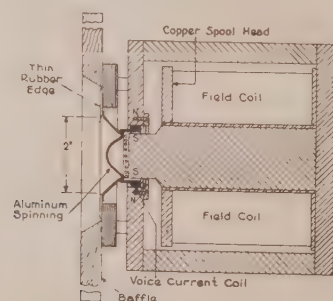
FIG. 7—BAFFLE-TYPE RIGID DIAPHRAGM, LOUD SPEAKER

dence, to offer the greatest promise of a practical solution of the loud-speaker problem, subsequent experiments were devoted to finding the best form of device embodying this principle. The first models left much to be desired in the way of sensitivity and considerable room for improvement in quality. The condition that

the diaphragm must move as a unit meant two alternatives; either the diaphragm must be very rigid for its weight and must be quite small, or the driving force must be applied uniformly over the entire diaphragm surface.

One of the most satisfactory forms of small rigid diaphragms is shown in Fig. 7. A somewhat similar instrument was designed for use with a horn and very good results were obtained[12]. A horn of adequate dimensions, however, is exceedingly bulky[13], and better
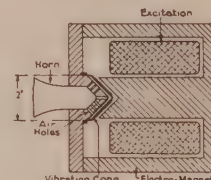
FIG. 8—COMMERCIAL GAUMONT LOUD SPEAKER

results were subsequently obtained with flat baffles.

Of the devices in which the actuating force can be applied over the whole diaphragm area, thus making rigidity unnecessary, the electrostatic phone and the Hewlett induction phone have already been mentioned.

Mr. Rice urged the probable value for the case of the small diaphragm instruments, of distributing the driving force over the entire diaphragm area, and believed that this could be done without sacrifice of field flux density. At this juncture a letter was received from Dr. W. R. Whitney describing a loud speaker which had been shown him in France by its inventor, Mr. Gaumont, and which fulfilled this condition.
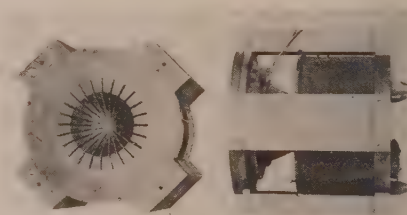
FIG. 9—GAUMONT TYPE LOUD SPEAKER ASSEMBLED

Fig. 8 shows the construction of the commercial loud-speaker built by the Société des Etablissements Gaumont. The diaphragm is a cone of thin silk, to which is cemented a single layer spiral of fine aluminum wire. An extremely light diaphragm is thus possible, making for sensitiveness and freedom from resonance. The reaction of the voice currents in the aluminum

12. A description is given in the *Wireless World* and *Radio Review* of Dec. 17, 1924, by Capt. H. T. Round, of a loud speaker resembling this in some respects.

13. "Function and Design of Horns for Loud Speakers" by C. R. Hanna and J. Slepian, JOUR. A. I. E. E., March, 1924. "The Performance and Theory of Loud Speaker Horns" by A. N. Goldsmith and J. P. Minton, *Proc.* I. R. E., Aug. 1924.

coil with the radial component of the magnetic field gives the useful driving force.

Figs. 9 and 10 show one of the Gaumont type loud speakers designed by Mr. Rice, for use with a baffle. The diaphragm support used in the commercial instrument shown in Fig. 8 does not afford sufficient flexibility. The substitution of a flat edge of thin rubber, as illus-
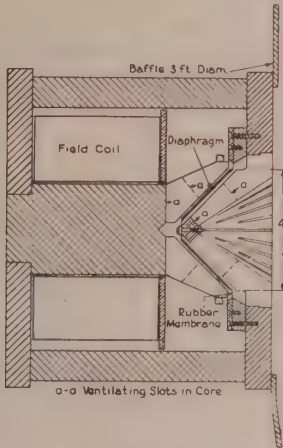
FIG. 10—MODIFIED DESIGN OF GAUMONT TYPE LOUD SPEAKER

trated in Fig. 10, gave the necessary flexibility without which adequate radiation of low tones from a small diaphragm had been found impossible. Experiments also indicated that a considerably heavier diaphragm than that employed in the commercial machine was required for good balance between high and low fre-
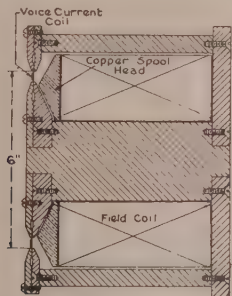
FIG. 11—CONSTRUCTION OF ANNULAR TYPE LOUD SPEAKER

quencies. The diaphragm which worked best was four inches in diameter and weighed 11 grams. It consisted of a single layer of copper wire embedded in rubber, which gave a soft, non-resonant structure. Adequate venting proved to be of utmost importance in this design in order that air reactions on the diaphragm might not affect its motion adversely and in order to let out the sound without muffling. A baffle 30-in. in diameter was employed.

An annular diaphragm type of loud speaker having uniformly distributed driving force is shown in Fig. 11. This instrument which was designed by Rice presents no venting difficulties and gives the possibility of

considerable diaphragm area. A thin rubber membrane spans the air-gap, and a single layer coil cemented to the membrane provides the driving force. A somewhat similar instrument used as a transmitter has recently been described by Round[14].

Efforts to gain sensitivity by the use of extremely light diaphragms have always, in our experience, led to disappointment. The expected gain in sensitivity was not realized, and in most cases the light diaphragm devices were very high pitched.
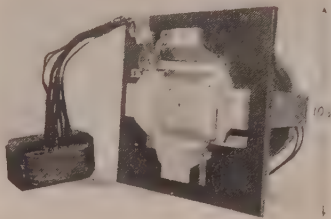
FIG. 12—ALUMINUM FOIL DIAPHRAGM LOUD SPEAKER WITH TRANSFORMER[15]

SEMI-RIGID DIAPHRAGMS

With the rigid type of diaphragms, a question to be settled experimentally was how large could the diaphragm be made before the quality of sound reproduc-
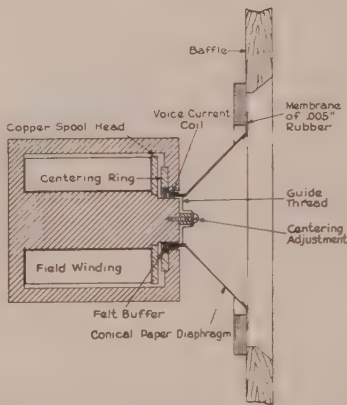
FIG. 13—CONSTRUCTION OF FREE EDGED, COIL-DRIVEN, CONICAL DIAPHRAGM LOUD SPEAKER

tion became impaired through failure of the diaphragm to act as a unit or plunger throughout the entire frequency range. A simple cone is an exceedingly rigid structure for its weight, particularly with respect to vibrations of the type which could be excited by a symmetrically applied force in the axial direction, such as is used in driving a conical diaphragm; or in other words, the cone is rigid with respect to vibrations

14. *Wireless World and Radio Review*, Nov. 26, 1924.
15. A loud speaker employing an aluminum strip in a magnetic field, manufactured by Siemens & Halske is described in "The *Wireless World and Radio Review*," July 2, 1924.

like the opening and closing of an umbrella. With an angle of 45 deg. between the axis and wall of the cone, the rigidity is practically at its maximum. Paper cones of various sizes were tried with free or flexibly supported outer edges, using baffles to prevent circulation and small coils as shown in Fig. 13 for drive. Diameters from 4 to 24 in. and angles from 45 deg. to 75 deg. were tried. These paper cones gave marked increase in sensitivity over the devices shown in Figs. 7, 10 and
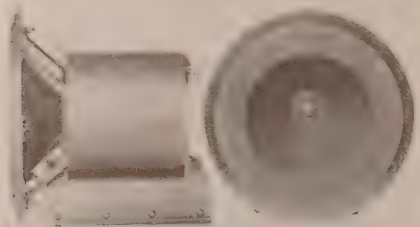
FIG. 14—FREE-EDGED, COIL-DRIVEN, CONICAL PAPER DIA-
PHRAGM LOUD SPEAKER UNIT

11, the general sensitivity on speech being at least equal to that of a good horn type loud speaker. Size seemed to have little effect on general sensitivity, but did somewhat alter the quality, diameters between four and eight inches giving the best results. The angle did not appear to be critical, but with very shallow cones speech sounded muffled, the high frequencies being lacking.

A rough calculation indicates that a 45 deg. paper cone 4 in. in diameter would begin to depart materially from rigid plunger action, at frequencies of between 3000 and 4000, while with larger diameter cones the change would take place at lower frequencies. The paper-cone diaphragms used in this series of tests must, therefore, be considered as acting substantially as plungers for the lower frequencies with a gradual transition to wave action or progressive deflection at the higher frequencies. If there was any loss of quality due to the failure of the diaphragm to move as a whole at high frequencies, there was a compensating improvement as compared with the small diaphragm instruments, in a better radiation of the low tones, for the small diaphragms did not give quite enough low frequency radiation. An extended series of tests was made to see whether a further improvement in quality could be obtained, making the cone of various materials and different thicknesses and by employing stiffening members to reduce the tendency of the cone to break up into vibrations either of the kind with circular nodes or with radial nodes. Nothing better was found, however, than a simple 45-deg. cone of 0.007 in. to 0.010 in. paper, about six in. in diameter, with a flexible support around the outer edge consisting of a membrane of rubber 0.005 in. thick and ¼ in. wide, under very slight tension. Fig. 13 shows the general construction of diaphragm and field,

and Fig. 14 shows views of two models of the instrument with baffles omitted. Leaving the center of the cone open as indicated in Fig. 13 simplified construction and avoided the necessity of venting the space in front of the magnet core. A baffle two feet square, appeared adequate. If the shortest air path between the front and back of the diaphragm is a quarter wave length or more there is no loss of radiation through circulation, although regions of interference between the two sound sources appear. An eight-foot wave length corresponds to a frequency of 135 cycles, and loss of output below this frequency may be attributed, in part, to circulation.

The baffle need not necessarily be flat, but if concave the solid angle included on the concave side should be at least as great as that in a cone with an angle of 45 deg. between wall and axis. With a smaller solid angle, resonance rapidly becomes noticeable and a change in general pitch level characteristic of horn action is brought about.[16]

In order that the diaphragm may vibrate as a whole, the support at the outer edge must be very flexible compared with the diaphragm itself.

COMPARISON OF DRIVING SYSTEMS

A low natural frequency means either a heavy diaphragm which would cost sensitivity, or else that the elastic restoring force supplied by the diaphragm supports plus any elastic restoring force in the driving

FIG. 15—CONICAL PAPER DIAPHRAGM WITH FREE OUTER
EDGE AND MAGNETO PHONE DRIVE

mechanism must be small. Electromagnetic driving systems with moving iron armatures all require a certain amount of elastic restoring force to maintain stability. The required stiffness may be reduced by (1) lengthening the air-gaps, (2) working with weaker average magnetic field, (3) using a lever system which makes the diaphragm motion greater than the change in air-gap length; all of which mean a sacrifice of driving force. Fig. 15 shows a model employing a free edge

16. "Effect of a Horn on the Pitch of a Loud Speaking Telephone," by E. W. Kellogg, General Electric Review, August, 1924.

cone with iron armature drive. By using a fairly large diaphragm and working close to the limit of stability it is possible to use this type of drive and obtain a low enough natural frequency and moderate sensitivity, but the moving coil drive has the following advantages: 1. The elastic restoring force may be made as low as desired without sacrifice of sensitivity. 2. Very large amplitudes can be allowed. (With a drive using variable length air-gaps, the change in gap length must always be small compared with the average length if distortion is to be avoided). 3. The relation between current and force is strictly linear, and there-

FIG. 16—MOVING COIL TYPE LOUD SPEAKER WITH PERMANENT MAGNET FIELD AND THREE-PASS HORN EXPONENTIAL HORN

fore distortion due to bends in the magnetization curves of iron is avoided in the moving coil drive. 4. If a strong magnetic field is provided the coil drive gives greater sensitivity than the iron armature drive. 5. No adjustment is upset if the weight of the diaphragm causes it to shift somewhat when the instrument is tilted. The disadvantages of the moving coil drive
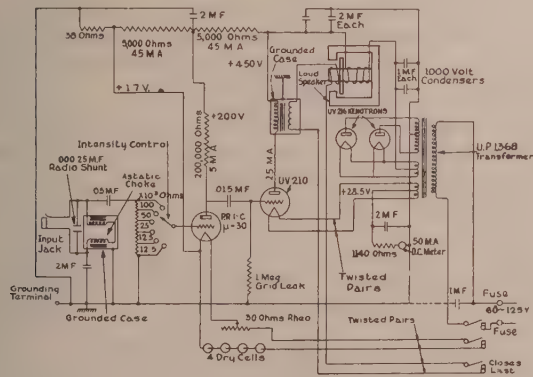
FIG. 17—RECTIFIER AND AMPLIFIER CIRCUIT

are the size and weight of the field magnet and the power required for excitation, but these disadvantages are outweighed by the advantages, in the opinion of the writers and their associates, particularly, when a special amplifier is part of the loud speaker equipment. A loud speaker with moving coil drive and permanent magnet field is shown in Fig. 15.

SPECIAL AMPLIFIER

As was pointed out by Martin and Fletcher[17] voices and music do not sound natural unless reproduced at approximately the original level of intensity, even though the reproduction may be free from all wave form distortion. In order, therefore, that the full

FIG. 18—LABORATORY MODEL OF CABINET SET—FRONT VIEW

benefit of a high grade loud speaker may be realized, it is important that the amplifier which goes with it should have sufficient capacity to give a natural volume or intensity.

Fig. 17 shows the circuits of an amplifier which has proved satisfactory for household service. Two U V-216 kenetrons rectify 70 milliamperes at 550 volts. The field of the loud speaker serves as filter choke. In order that pulsations in the rectified current in the exciting coil may not cause changes in the air-gap flux and

FIG. 19—LABORATORY MODEL OF CABINET SET—BACK VIEW

thereby produce hum and modulation of the sound output, the head of the spool on which the field coil is wound is made of copper one-fourth inch thick. This expedient suggested by Kellogg steadies the flux so that there is almost no ripple. About 100 volts are dropped in the field coil, leaving 450 volts for the plate supply of the U V-210 radiotron which serves as the power tube. A bias of about 28 volts is required for the grid, and this bias is obtained by dropping 28 volts in a resistance so that the filament runs at a mean potential of + 28 volts with respect to the negative terminal of the recti-

17. "High Quality Transmission in Reproduction of Speech and Music," by W. H. Martin and H. Fletcher. JOURN. A. I. E. E., March, 1924.

"Physical Measurements of Audition and their Bearings on the Theory of Hearing," by H. Fletcher. *Jour.* Franklin Inst., Sept., 1923.

fier. This makes the net plate voltage across the tube about 422, and the mean plate current is 25 milliamperes. Under these conditions an average U V-210 radiotron can send 10 milliamperes, r. m. s. value, of sine wave current through a 10,000 ohm load without appreciable wave distortion.[18] This represents about thirty times as much power as the same tube could put out with a plate supply of 120 volts.

Cabinet Set

Figs. 18 and 19 are views of a laboratory model of a cabinet set containing rectifier, amplifier and loud speaker. The front of the cabinet acts as baffle. To prevent air resonance in the box, the sides and back are vented by inserting panels of perforated brass. The ammeter shown in the picture is connected to read the plate current of the radiotron. Whenever the peak values of the voltage applied to the grid of the tube exceed the value for which distortionless operation is possible the meter needle shows disturbance. If roughness commonly termed "blasting" is noticed in the reproduction, and if at the same time the meter needle kicks, the intensity of the input should be reduced. If the meter needle is steady, the fault is probably not in the amplifier.

Psychological Factors

Certain experiences connected with testing and demonstrating loud speakers of the type we have described are of interest. The possession of an instrument in which distortion is minimized and whose response covers a wide frequency range, transfers the interest of the broadcast listener from "fishing" for distant stations to that of trying to find the best program among the near-by high grade broadcasting stations, and to enjoying the music or speeches themselves.

There are, on the other hand, conditions when the difference between the loud speaker with a wide frequency range, and one of the ordinary horn type which loses both very high and low frequencies, is not at all striking, and the latter may even sometimes be preferred. Measurements of sound intensity required for audibility[19] show that as intensity is reduced, the low tones will be lost first, since the threshold intensity for example of a 100 cycle tone is of the order of fifty times that for a 1000 cycle tone, intensity being expressed in sound wave pressure. As a result of this, when the reproduction as a whole is very faint, the instrument which produces the low tones does not sound materially different from one which does not, for even if reproduced in the correct relative intensity compared with the higher tones, the low tones are below audibility.

When a radio program is half smothered in static, it

18. Design of Distortionless Power Amplifiers, by E. W. Kellogg, A. I. E. E., 1925 Mid-winter convention.

19. Physical Measurements of Audition and their Bearing on the Theory of Hearing, by H. Fletcher, *Journ.* Franklin Inst., Sept., 1923, Bell System *Tech. Jour.* Oct. 1923.

may sound better through a loud speaker whose response is mainly between 500 and 2000 cycles, than through one having a greater range. The energy in the incoming static is likely to be almost uniformly distributed over the audio frequency range, provided the receiving set is not responsible for distortion, whereas the range 500 to 2000 cycles includes the major part of the essential voice frequencies. Extending the range above and below would add to clearness and naturalness in the absence of interference, but with heavy static it may often bring in enough additional disturbance to more than offset the gain. Lack of clearness may be less irritating to the listener than disturbing noises. Hence the enjoyment of the wide range loud speaker is largely confined to strong stations or else to times of comparative freedom from static. A similar observation applies to roughness caused by "blasting" from overworked amplifiers or other causes. When any piece of acoustic apparatus is worked beyond the maximum amplitude for which the output bears a linear relation to the input, the resulting wave-distortion takes the form of the production of overtones. The rough harsh sounds which result are much less noticeable with an instrument which cuts off the high frequencies. Therefore, if the improved articulation and greater detail in music, which are made possible by response to high frequencies, are to be a real advantage, we must avoid the faults just mentioned in the currents supplied to the loud speaker. The logical place to begin is the amplifier associated with the loud speaker. This must be carefully designed and have ample capacity so that there will be little temptation to overwork it. Few pieces of apparatus are so frequently worked beyond their proper capacity as loud speaker amplifiers. This is natural in view of the initial expense of an adequate amplifier, and the desire for volume of sound from the loud speaker. With the usual type of loud speaker a slight overworking of the amplifier is hardly noticed, and rather than provide greater amplifier power, users of loud speakers have compromised with low volume and some amplifier distortion, and either educated their ears to accept the result as good, or else lost interest.

Another factor bears on the question of amplifier capacity. With distortion such as is usual in receiving sets and loud speakers the reproduction sounds best when weak, perhaps because the distortion is similar in some respects to the effects of distance. Use of such equipment results in one's forming the habit of enjoying faint music. With more nearly correct reproduction of the original music, enjoyment is increased by bringing the volume up to normal or the intensity to which one is accustomed when listening directly. In several instances it has been observed that when a loud speaker of the new type has been placed in the home of some one previously accustomed to a loud speaker of the usual construction, at first the listener preferred to keep the intensity very low, but after a few days we find him working with normal volume.

OUTPUT MEASUREMENTS

Up to the time of writing the authors have not been able to obtain sound output measurements under conditions with which they were completely satisfied, but it is expected that some sound pressure data will be ready in time to submit as discussion.

ACKNOWLEDGMENTS

The writers wish to express their deep appreciation for the never failing interest and encouragement given by Dr. W. R. Whitney throughout the long, investigation. We are also greatly indebted to our colleague, Dr. C. W. Hewlett, for many helpful suggestions and for the production of our first really high-grade loud speaker which was constantly used as a standard of comparison. We are further indebted to Mr. E. P. Lawsing for able assistance in the experimental work and to Mr. W. F. Winter in the mechanical construction.

Rules and Personnel Problems of the Marine Field

By Committee on Applications to Marine Work[1]

IT is believed that the report of the Committee on Application to Marine Work for this year may be said to be the most comprehensive of any similar reports for the past few years.

The main proposition on hand for this year was the revision of the existing Marine Rules. These rules were issued about five years ago, and at that time were more or less of a tentative draft, and had become somewhat outlawed by changes in the art. Due to the fact that the Sectional Committee of the American Engineering Standards Committee did not seem to be functioning with sufficient rapidity to insure a recognized standard within the near future, the Marine Committee voted last Fall to re-edit and publish a revised set of Marine Rules, and for the past year, practically all of the time of the Committee and Subcommittees has been devoted to this line.

In the above connection, exceptional credit must be given to last year's Chairman and the Chairmen of the other Subcommittees for their untiring efforts and cooperation to bring about the desired results.

Among a few of the details which have been under consideration, and in some cases accomplished, may be mentioned the following:

a. A member of our Committee has been appointed to represent the A. I. E. E. on the Marine Standards Committee.

b. The 1923 proceedings of the National Fire & Protective Association adopted the Marine Rules in so far as they applied to insurance.

c. The British Consul requested the Committee's advice in regard to using magnetic cranes in shipyards.

d. A member of this Committee addressed the Boston Section in March, on the subject of the Merchant Marine, especially covering the point of responsibility of electrical operators, and the failure of the U. S. Steamboat Inspection Service to recognize its responsibilities.

e. In the report of the meeting of November 1924, was included an item of Publicity, giving a bibliograph of recent data which had been published in various magazines, as applying to Marine Electrical Industry.

It is believed that an extension of this service by the Institute would be a desirable undertaking, (possibly in cooperation with Mechanical Engineers) in connection with the Engineering Index. We understand that this matter is now under consideration, and the Committee most heartily endorses the proposition.

The most important work of the Marine Committee of this year is contained in the conference held on Thursday morning at the St. Louis Convention, at which session there were three articles presented: one covering the History of Electrical Application to Marine Work up to date; another, the Application of Electrical Propulsion; and a third, covering Merchant Installations and Electrical Operators, with special reference to the licensing of electrical engineers.

It is believed that a survey of these three articles may be considered as a very definite progressive report of the work of this Committee for the year, and suggestion is made that all interested might peruse these three articles to advantage.

In connection with the suggested work of next year, the recommendation would be, if possible, to develop an inspection to include electrical devices for marine use. Also, possibly, to extend the scope of the Committee to include certain branches of manufacturing as are not already included within the scope of our Marine Rules, such as Instruments, etc. Also, there will no doubt develop certain phases of the present rules that will need further revision, and the development of rules as suitably applying to electric propulsion.

1. Annual Report of the Committee on Applications to Marine Work.

L. C. Brooks, Chairman
H. Franklin Harvey, Jr., Vice-Chairman
J. S. Jones, Secretary

R. A. Beekman,	H. L. Hibbard,	Arthur Parker,
J. F. Clinton,	William F. James,	G. A. Pierce,
M. W. Day,	J. S. Jones,	H. M. Southgate,
C. S. Gillette,	M. A. Libbey,	W. E. Thau,
Wm. Hetherington, Jr.,	W. F. Meschenmoser,	A. E. Waller.
	I. H. Osborne,	

To be presented at the A. I. E. E. Annual Convention, Saratoga Springs, N. Y., June 24, 1925.

A High Frequency Induction Furnace Plant
For the Manufacture of Special Alloys

BY P. H. BRACE*

Non-member

Synopsis.—*High-frequency induction furnaces have been used for some time for the laboratory preparation of special alloys on a relatively small scale, and, to a limited extent, on a commercial scale. High-frequency power has, in general, been secured from spark-gap oscillation generators. Recently the Westinghouse Electric & Manufacturing Company installed a plant having a nominal capacity of 20 tons per month, in which alloys are being produced in high-frequency induction furnaces supplied with power from a 100-kw., 5000-cycle inductor-type alternator. Zirconium silicate finds extensive use for furnace linings and thermal insulation. Alloys of great purity, which meet unusual and severe requirements, are being produced at a cost which compares favorably with that of ordinary commercial materials of the same nominal composition but having much inferior properties.*

THE plant described in the following paper was developed for the express purpose of manufacturing, on a commercial scale, metals and alloys of the same degree of purity, and having the properties of those heretofore available only as the result of costly small-scale laboratory production. The general plan of operation has been to melt the purest metals obtainable under conditions insuring the minimum of contamination, and very gratifying results have been obtained by the use of electrolytic metals and high-frequency induction furnaces of the type originated by Dr. E. F. Northrup.

The equipment of this plant falls into three main groups as follows:

1. Electrolytic iron refinery.
2. High frequency power plant.
3. High frequency furnace plant.

The description which follows will be divided along these lines.

ELECTROLYTIC IRON REFINERY

The electrolytic refining of iron is no new thing, and the practise followed in this plant does not differ fundamentally from that found successful in the laboratory. The electrolyte is a distilled-water solution of the best grade of technical salts, as given by Table I.

Chemical control of the plant is maintained by periodical analysis of the electrolyte, to determine the acidity and concentration of iron as well as the proportions of the other components. The acidity is measured by electrometric titration in terms of the hydrogen ion concentration.

In practise, it has been found that the concentration of the electrolyte and the relative proportions of the component salts may vary over a considerable range without causing serious difficulty. Satisfactory deposits are obtained with the iron concentration within limits of 45 and 55 grams per liter, and with the hydrogen-ion concentration between 1.5×10^{-6} and 0.7×10^{-6}.

*Research Engineer, Westinghouse Electric & Mfg. Co.

Presented at the Spring Convention of the A. I. E. E., at St. Louis, Mo., April 13-17, 1925.

The acidity is adjusted by addition of hydrochloric acid or ammonia, the latter being very conveniently added by injection into the circulating system from a tank of liquid ammonia.

The temperature of the electrolyte ranges between 25 deg. and 35 deg. cent. the only heat supplied being that due to the passage of the electrolyzing current.

In order to clarify the electrolyte and maintain uniformity of composition, it is circulated continuously through a nine-foot, five-tray Dorr thickener. The chief difficulties in the operation of the plant have been connected with the circulation and clarification of the electrolyte. These have been due to the fact that

TABLE I
Composition of Electrolyte

Salt	Quantity	Concentrations (group per liter)			
		Fe	Cl	SO₄	NH₄
FeCl₂. 4 H₂0	75 grams per liter (4.7 lb. per cu. ft.)	21.1	26.8		
FeSO₄. 7 H₂O......	150 grams per liter (9.4 lb. per cu. ft.)	32.0		45.5	
(NH₄)₂ SO₄.........	100 grams per liter (6.25 lb. per cu. ft.)			68.0	31.2
	Totals.....	53.1	26.8	113.5	31.2

aeration of the electrolyte from any cause results in oxidation of the ferrous salts and the precipitation of the iron as basic hydrates. As the removal of the iron proceeds, the acidity of the electrolyte rises, and shiny, brittle, deposits are produced, which peel from the cathode sheets and fall to the bottoms of the tanks. It has been necessary to arrange the pumps and piping and the inlets and outlets of the tanks so as to avoid turbulent flow and prevent entrainment of air. Clarification of the electrolyte is necessary to prevent contamination of the deposited iron by inclusions of sludge from the anodes.

The anodes are made from hot-rolled slabs of Armco iron two inches (5.1 cm.) thick by 28 inches (71.2 cm.) wide by 40 inches (102 cm.) long. They are supported in the tanks by two L-shaped lugs, arc-welded to the corners of the slabs at one end.

The cathodes are cut from ordinary soft steel sheets. They are clamped between brass bars which support them in the tanks. The general appearance of the anodes and cathodes is shown in Fig. 1. The anode at the right has been in service for some time and the uniformity of the corrosion is noteworthy. The cathode shown has received a deposit approximately ¼ inch (0.6 cm.) thick, and will be ready for stripping when the deposit is approximately ⅜ inch (0.9 cm.) thick.

Armco iron was chosen for anode material because it was but slightly more expensive than other suitable material and because its very small content of impurity would minimize the contamination of the electrolyte by foreign metals and sludge.

A large proportion of the insoluble impurities remains on the surfaces of the anodes as the iron is eaten away and forms a black, somewhat gelatinous, coating which interferes with the corrosive action of the electrolyte. If this sludge is allowed to accumulate, the bath will become impoverished in iron; therefore, the anodes are removed from the tanks about every

FIG. 1—ELECTROLYTIC IRON REFINERY CATHODE (LEFT) WITH ¼ IN. (0.6 CM.) DEPOSIT OF ELECTROLYTIC IRON; ANODE (RIGHT) AFTER APPROXIMATELY FOUR WEEKS' USE. NOTE UNIFORM CORROSION

third day and washed with a strong stream of water from a hose.

The cathode sheets are prepared for receiving deposits by cleaning to remove grease and rust and heating in a gas furnace to a dull red heat for a short time. A thin coating of black iron oxide is produced which prevents strong adhesion of the deposits and makes it an easy matter to strip the electrolytic iron from the sheets.

Carbon and sulphur are the most objectionable impurities. The former is removed very completely by electrolytic refining, as it remains in the tanks as part of the sludge. The sulphur in the original iron is not transferred, but some sulphur is introduced by the occlusion of electrolyte in the deposit. Analysis of a sample of good electrolytic iron by the "evolution" method will show a sulphur content of the order of 0.002 per cent or less. The same sample may show a sulphur content of 0.015 per cent when analyzed by the

"oxidation" method. The latter method should always be used when analyzing electrolytic iron for sulphur because it determines the sulphur present as sulphates as well as that present as sulphide, while the evolution method shows only sulphide sulphur.

The deposits on the cathodes are allowed to build up to a thickness of approximately ⅜ inch (0.9 cm.) and are then washed for 48 hours in hot water agitated by steam jets. Two changes of water are used. By this

TABLE II.

Outline Specification for Electrolytic Iron Refinery

Total floor space	71 ft. (21.6 m.) x 32 ft. (9.7 m.)
Output	700 lb. (310 kg.) per 24 hr.
Current	2000 amperes maximum
Current density	10-12 amperes per sq. ft. (120-144 amperes per sq. m.)
Voltage	20 maximum
Power supply	50 kw., 2000 amperes, 20 volts separately excited, d-c. generator with field control, driven by 70-h.p., 2200-volts, 3-phase, 60-cycle induction motor.
Tanks	18 wooden tanks, connected in series, each containing 10 anodes and 9 cathodes. The tanks are 3 ft. (91 cm.) wide by 6 ft. (183 cm.) long and 4 ft. (122 cm.) deep inside.
Piping	Lead and stoneware.
Fitting, valves	Durion.
Pumps	Two Durion centrifugal pumps, rated at 100 gal. per min. (37.8 l. per min.) at 50 lb. per sq. in. (3.5 kg. per sq. cm.) driven by direct-connected 10-h. p., 220-volt, 3 phase induction motors.
Clarification	9 ft. (275 cm.) diameter, 5-tray Dorr thickener, operating with a flow of 50 gal. per min. (188 l. per min.).
Anodes	Armco iron, 2 inches (5.1 cm.) by 28 inches (69 cm.) by 40 inches (102 cm.)
Cathodes	Sheet steel. 1/16 in. (0.15 cm.) by 30 inches (76 cm.) by 40 inches (102 cm.) with coating of black oxide to prevent sticking of deposits.

FIG. 2—GENERAL VIEW OF ELECTROLYTIC IRON REFINERY. DORR THICKENER INSTALLED BEYOND PARTITION AT FAR END. MIXING TANKS, LEFT-CENTER. WASHING TANKS, EXTREME LEFT

means the total sulphur can be kept below 0.01 per cent and occasionally as low as 0.006 per cent. After washing, the deposits are stripped, broken by hand hammers to approximately two inch (5 cm.) size and stored ready for melting.

The principal data concerning this plant have been summarized in Table II, and Fig. 2 gives a general view of the installation.

HIGH FREQUENCY POWER PLANT

High frequency power for the induction furnaces is furnished by a motor-generator set designed and built especially for this work. This machine was designed by C. M. Laffoon of the Power Engineering Department, Westinghouse Electric and Manufacturing Company, and has been described by him in some detail*. The alternator is of the inductor type with a cylindrical rotor, and operates normally at 3750 rev. per min., giving a frequency of 5000 cycles per second at this speed. The machine delivers 400 amperes continuously at 250 to 300 volts, corresponding to an output of 100
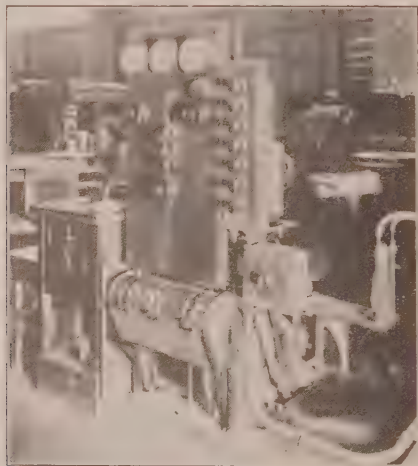
FIG. 3—CONTROL PANEL FOR HIGH FREQUENCY POWER PLANT. FURNACES AND DRIVING MOTOR OF HIGH FREQUENCY ALTERNATOR SEEN IN BACKGROUND AT RIGHT.

to 120 kv-a. Under these conditions there have been no indications of excessive temperature rise in the windings, and the mechanical performance has been excellent under all conditions. The alternator is driven through a standard Westinghouse turbine reduction gear, giving a speed ratio from generator to motor of 4.12 to 1. The motor is a standard Westinghouse Type S K motor, rated at 200 h. p., 230 volts, 910 rev. per min. provided with field control to give a frequency range from 4500 to 6000 cycles per second.

The entire control of the high-frequency power supply is centered in the control panel shown in Fig. 3. This panel carries the following equipment.

1. Relay switch for operating the automatic motor-starting equipment.

2. Motor field rheostat for controlling motor speed.

3. Field switch for high frequency generator.

4. Field rheostat for high frequency generator.

5. Push-buttons controlling the solenoid-operated condenser switches.

6. Frequency meter calibrated in cycles per second

*High Frequency Alternators, by C. M. Laffoon: *Electric Journal*, Sept. 1924, Vol. XXI, No. 9, p. 416-420.

and operating from a speed-indicating magneto direct-connected to the motor shaft.

7. Direct-current ammeter for measuring field current of high-frequency alternator.

8. Thermal ammeter for measuring high-frequency generator output.

Thus, one man has complete control of the starting and stopping of the high-frequency generator, of frequency, of condenser capacity, and of the voltage and current output of the alternator. For a given material and weight of charge, the furnace operations soon reduce to a routine matter of shoveling in the charge and the following of a definite current-time schedule.

The windings of the alternator are divided into twelve similar sections,—six on each end of the stator,—and these are operated in series-parallel connection, giving six groups, each having two coils in series. These six groups are connected in parallel to the bus-bars through 60-ampere, 500-volt fuses and the equalizing transformers. The purpose of the equalizing transformers is to ensure equal division of current among the paralleled
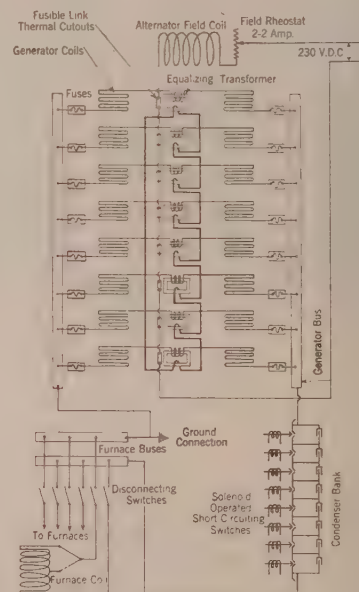
FIG. 4—SCHEMATIC DIAGRAM OF CIRCUITS OF HIGH FREQUENCY ALTERNATOR, CONDENSERS AND FURNACES

sections of the windings. Previous experience with a small alternator of this same type showed that it was very difficult to get similar characteristics in all the coils, and that the relative characteristics of the coils would sometimes change appreciably with time, because of alterations produced in the dimensions or relative positions of the parts of the machine by temperature changes or other causes. As a result, it was impossible to form a grouping which would give an equal distribution of load under all conditions.

Fig. 4 is a schematic diagram of the generator, equal-

izing transformer, condenser and furnace circuits. From this it will be seen that the equalizing transformers consist of cores with a primary winding on each and that one of these primary windings is in series with each series pair of generator coils. All the cores are linked with a common secondary winding which is short-circuited on itself. Thus, the secondary current is always alike in all the transformers and the tendency is to maintain the equality of the primary currents; hence equal distribution of current among the various coil groups. If, for any reason, an open circuit develops in
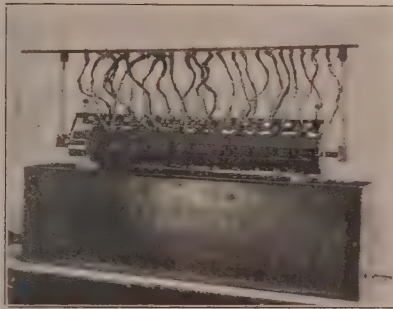
FIG. 5—SHOWING TRANSFORMER TANK, CORES SURROUNDED BY SECONDARY CIRCUIT, FUSIBLE-LINK THERMAL CUT-OUTS AND LEADS TO PRIMARY COILS

any coil group, the iron of the corresponding transformer core is immediately subjected to the full magnetizing force due to the secondary current impelled by the remaining transformers, and destructive temperatures are soon reached. The transformers are safeguarded against this contingency by placing a link of low-melting alloy in the oil immediately above each core. These links are connected in series with the field coil of the alternator. Hot oil rising from any overheated core melts the corresponding fusible link. This interrupts the field current and protects the transformer, while, at the same time it gives notice of trouble to the operator. This arrangement has worked satisfactorily on the few occasions when accidental overload has caused rupture of a fuse in series with one of the coils.

Fig. 5 shows the structural details of a group of equalizing transformers. The cases for the fusible links are seen above the cores. The common secondary consists of a copper tube, (to allow water cooling), which passes through the toroidal cores, and is provided with end plates connected by flat copper bars to complete the circuit. The cores consist of stacks of 5 mil enameled four per cent silicon steel ring punchings.

The alternator is connected in series with the furnace, inductor coil and the bank of condensers, as shown diagrammatically by Fig. 4. This condenser installation was designed by R. E. Marbury, Supply Engineering Department, Westinghouse Electric & Manufacturing Company and has been described

elsewhere*. Westinghouse oil-insulated paper condensers, such as are regularly used for 2300-volt power-factor correction service, were used to build up this bank of condensers. The individual units have a capacity of 1.21 μf. and there are eight groups of them, each containing 20 units in parallel. Each group is provided with a remote controlled short-circuiting switch and adjustment of the condenser capacity is effected by manipulating these switches to vary the number of condensers in the circuit. Table III shows the great flexibility made possible by this arrangement.

TABLE III.
Capacity Range of Condenser Bank

No. of Groups in Circuit	Max. Total voltage	Capacitance microfarads	Max. Total Kv-a.
8	4650	3.2	2040
7	4050	3.46	1780
6	3500	4.02	1540
5	2900	4.85	1275
4	2320	6.05	1110
3	1740	8.07	765
2	1160	12.10	510
1	580	24.2	255

The condensers are mounted in grounded structural iron frames, from which they are insulated by porcelain insulators designed for a maximum stress of 10,000 volts. Much ingenuity was exercised in arranging the electrical circuits within the iron frame in such a way as to avoid
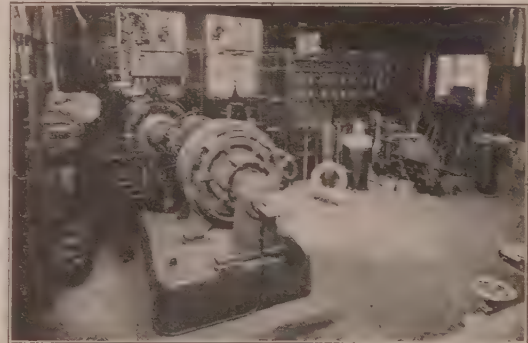
FIG. 6—GENERAL VIEW OF HIGH FREQUENCY POWER PLANT. FROM LEFT TO RIGHT, AUTOMATIC CONTROLLER, HIGH FREQUENCY MOTOR-GENERATOR SET, CONDENSER BANK, 225-LB. FURNACE, VACUUM PUMPS, CONTROL PANEL (FROM REAR), VACUUM FURNACE

heating of the iron work by the high-frequency magnetic field surrounding the bus-bars and no trouble has been experienced from this cause. The condenser frames and condenser switches are enclosed in a grounded, expanded, metal housing. Bus-bars are carried around the top of the condenser frame and disconnecting switches are placed at intervals, and the several furnaces are supplied with power through these switches

*The Application of Static Condensers to High Frequency Furnaces, by R. E. Marbury: *Electric Journal*, Sept. 1924, p. 421-422.

which are hand-operated by means of the usual wooden hook-stick.

This condenser installation is much more elaborate than would usually be necessary, and was made so purposely in order to provide flexibility, for, although the plant as a whole was designed as a productive manufacturing unit, the expectation was that it would also serve as an experiment station for the practical development of other applications for high frequency power, particularly in connection with heating problems. In passing, it may be said that this expectation has been fully realized.

Fig. 6 shows a general view of the motor-generator set, condenser bank, and a furnace being assembled for charging.

High-Frequency Furnaces

The high-frequency furnaces used in this plant are the same in principle as those which Dr. E. F. Northrup has so successfully developed for use with high frequency power derived from spark-gap oscillators. Slight modifications in design have resulted from the fact that the applied voltage is practically sinusoidal instead of being a series of impulses, as in the case of the spark-gap oscillator. From an electrical standpoint, a high-frequency furnace may be considered as a special case of the transformer. Physically it consists essentially of a water-cooled helix of copper tubing surrounding the material to be heated. The magnetic field produced by high frequency current traversing the coil, or primary, induces voltage in the charge, or secondary, and the resulting currents cause heating. It will be obvious that if the resistivity of the charge is very high or very low the heating effect will be small, for, in the first case only negligible currents will flow, and in consequence, the product $I^2 R$ will be small, while in the second case, low resistance will result in a small $I^2 R$ product. In practise, satisfactory heating is obtained at 5000 cycles per second when the resistivity of the material to be heated lies between the approximate limits of 50 and 1000 microhms per centimeter cube and when the pitch of the coil and the current through it are such as to give approximately 500 ampere-turns per inch as a minimum. The efficiency of the furnace will increase as the rate of heating is increased because as the time required to reach a given temperature is reduced, the heat lost by conduction becomes a smaller proportion of the total amount supplied.

As in the case of the ordinary transformer, the closer the electromagnetic coupling between the primary and secondary, the higher the power factor and electrical efficiency. In the case of the furnace, however, close coupling requires close approach of inductor and charge, and a point is reached at which the gain in electrical efficiency due to improving coupling is counterbalanced by the loss in thermal efficiency resulting from decreasing thermal insulation. The optimum coupling is not a constant but depends upon the rate of energy supply,

the temperature to be reached and the nature of the temperature cycle. The coupling coefficient will be denoted by ϕ and is defined as the fraction of the total magnetic flux produced by the coil which is linked with the charge. Roughly it is proportional to the ratio of the square of the diameter of the charge to the square of the diameter of the coil. For most high-temperature melting operations satisfactory performance is obtained when this ratio lies between the approximate limits of 0.5 and 0.7, and a usual value is 0.6. In a general way, the coupling giving the best results will approach the lower limit when it is desired to reach the maximum temperature with a given amount of power, and will approach the upper limit when a given temperature is to be quickly reached by generous application of energy.

The accurate calculation of the electrical characteristics of a given combination of inductor and charge is a matter of considerable difficulty, not only because of the purely mathematical problems of determining the effective resistances and reactances of the coil and the charge, but also because of our ignorance of the electrical and thermal properties of conductors and refractories at high temperatures. Northrup[*] has developed approximate formulas which are found to be sufficiently accurate for most engineering purposes when the frequencies are high enough to justify the assumptions:

1. That the effective ohmic resistance of the charge is equal to its reactance.

2. That the resistance of the inductor coil is negligible compared to its reactance.

Two of these formulas are particularly useful in designing furnaces to operate on given voltage and frequency, and are given below.

$$P = \frac{2 \phi E^2}{2 \pi^2 f L (\phi^4 + 2 - 2 \phi^2)} \qquad (1)$$

$$P = \frac{0.45 \phi E I}{\sqrt{\phi^4 + 2 - 2 \phi^2}} \qquad (2)$$

Here, P is the power absorbed by the furnace: ϕ is the fraction of the total flux produced by the coil which is linked with the charge; E is the root mean square voltage across the coil; I is the current through it and L is its inductance.

In designing the furnaces for the plant here described, we have used somewhat different design methods, as outlined below.

1. Given: An ingot of a certain size and material to be melted.

2. Required: An estimate of the length, diameter, number of turns of the inductor, and the range of condenser capacity and kv-a. required for operation

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*Electric Heating by Ironless Induction, by E. F. Northrup: *General Electric Review*, Nov. 1922, Vol. XXV, No. 11, p. 656-666.

*Principles of Inductive Heating by High Frequency Induction, by E. F. Northrup: *Transactions* Amer. Electrochem. Society, Vol. XXXV, 1919, p. 69.

with a power supply of which the voltage, current and frequency are given.

3. Experience was drawn upon to make a plausible estimate of the ampere turns per unit length of the inductor, and also to select a reasonable ratio for the diameters of inductor and charge.

4. The axial length of the inductor coil is determined by the length of the charge, and it has been our practise to make it somewhat greater than that of the charge, the excess in general not exceeding the diameter of the charge.

5. From (3) and (4) the dimensions of a trial coil are found. Its inductance is calculated, and from this and the given values of current and frequency, its reactive voltage and kv-a. are found.

6. The electrostatic capacity required to resonate at the assigned frequency with the inductance determined in (5) is calculated, using the formula,

$$C = \frac{1}{4 \pi^2 f^2 L}$$

where C is the capacity in farads: f, the frequency in cycles per second: and L the inductance of the coil. This establishes the maximum voltage and kv-a. rating for the condenser and the minimum value for its electrostatic capacity.

7. The effective resistance of the inductor is calculated from its direct-current resistance in the light of test results. Test data are available which show that for frequencies between 5000 and 10,000 cycles per second the high-frequency resistance of the usual furnace coils will be from 5 to 25 times the direct-current resistance. For $\frac{1}{2}$ inch (1.27 cm.) by $\frac{3}{4}$ inch (1.9 cm.) copper tubing flattened to 0.45 inch (1.14 cm.) and edge-wound with a pitch of two turns per inch (0.79 turns per cm.) the a-c. resistance is approximately 25 times the d-c. resistance for coils having proportions usually encountered in furnaces, the length-diameter ratio being of the order of two to three.

8. The resistance of the charge is calculated on the assumption that it is a thin cylindrical shell of which the length and outside diameter are those of the charge, and the thickness is given by Steinmetz's* formula for the depth of penetration of current in a conductor,

$$L_p = \frac{5030}{\sqrt{\lambda \mu f}}$$

where
L_p is the effective depth of penetration in centimeters:
λ the conductivity of the material in reciprocal ohms per cm.[3]:
μ the magnetic permeability of the material and
f, the frequency in cycles per second.

9. The inductance of the charge is calculated by assuming that it is a very thin cylindrical shell whose

mean length and mean diameter are those of the shell given by (8).

10. The mutual inductance of coil and charge are calculated by means of the approximate formula,

$$M = \frac{2\pi^2 A_2{}^2 n_1 n_2}{d \times 10^9} \quad \text{and}$$

$$d = X\sqrt{1 + \left(\frac{A_1}{X}\right)^2}$$

where
M is the mutual inductance in henries:
A_2 the means radius of effective current zone in charge in centimeters:
n_1, the total turns on coil;
n_2, the total turns on charge $(= 1)$;
X, the half length of the coil, and A_1 the effective radius of the coil in centimeters.

11. The effective inductance of the coil when the charge is in place will be less than that of the coil alone, and is calculated from the formula given by Morecroft,*

$$L_1{}^1 = L_1 - \left(\frac{\omega M}{Z_2}\right)^2 L_2$$

where
$L_1{}^1$ is the effective inductance of coil with charge;
L_1, the inductance of the coil alone;
ω, the product $2\pi \times$ frequency in cycles per second;
M, the mutual inductance of coil and charge;
L_2, the inductance of the charge and
Z_2 the impedance $(\sqrt{R_2{}^2 + L_2{}^2})$ of the charge.

12. The effective resistance of the coil will be increased by the introduction of the charge because of energy absorption by the latter. The effective resistance of the coil when surrounding the charge is calculated by a formula given by Morecroft.†

$$R_1{}^1 = R_1 + \left(\frac{\omega M}{Z_2}\right)^{\prime\prime} R_2$$

where
$R_1{}^1$ is the effective resistance of the combination of coil and charge:
R_1, the high frequency resistance of the coil alone:
R_2, the resistance of the charge as calculated in (8).

13. The minimum values of the reactive kv-a. and voltage of the coil and hence of the condenser, and the maximum electrostatic capacity required, are determined by the effective inductance of coil and charge as calculated under (11) on the assumption that the condenser capacity will be adjusted to give resonance at the chosen frequency.

14. The effective resistance of the condenser is calculated from a knowledge of its power factor as

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*Transient Electric Phenomena and Oscillations, by C. P. Steinmetz: 1909 Edition, p. 376.

*Principles of Radio Communication: Morecroft, p. 87.
† loc. cit.

determined by test, and the kv-a. corresponding to a given current.

15. The maximum power and current which will be taken by the furnace at the given generator voltage is then calculated by summing the resistances given by .12) and (14), and any circuit resistance which may enter, and applying Ohms' law, assuming operation at resonant frequency so that the inductive reactance of the furnace circuit is balanced by the capacitive reactance of the condenser, and hence that the apparent resistance between the terminals of the condenser-furnace circuit is equal to the true ohmic resistance.

16. The power input to the charge is found by subtracting the copper losses in the coil (determined from its high frequency resistance and the current) from the total power as determined by (15). The maximum temperature obtainable can be found approximately by calculating the thermal resistance of the refractories separating charge and coil, and from this the temperature drop from charge to coil required to transfer the thermal equivalent of the power input to the charge.

17. Having thus arrived at a tentative design for the inductor coil and an approximate estimate of its performance, the final design can usually be obtained by a second approximation with sufficient accuracy.

In practise, it has been found that the method outlined above gives very good results so far as the determination of condenser capacity and coil voltage are concerned. The results for maximum temperature obtainable and the effective resistance of the coil with charge are less accurate. This is due to the approximations necessary in the calculation of the copper losses in the coil and the effective resistance and inductance of the charge (hence the effective resistance of the coil with charge) and to uncertainty as to the true values of the electrical and thermal properties of materials at high temperatures. Table IV gives a comparison of the results of calculation and test for a certain melting furnace.

Fig. 7—50-Lb. Vacuum Furnace

The actual construction of two types of furnace now in use is shown by Figs. 7 and 8.

Fig. 7 is a vacuum furnace designed to melt 50-to 60 lb. charges of iron. The vacuum jacket enclosing the furnace proper consists of a micarta tube to which micarta duck-end plates are sealed by means of a special wax. The furnace proper consists of a slightly tapered helix of copper tubing supported on radial asbestos abutments carried within a second micarta tube. Water and electrical terminals are brought out from both ends and the middle of the coil. Above the coil

TABLE IV.
Comparison of Calculation and Test Data for 50-lb. Vacuum Furnace

	Resonant Frequency (with full charge)	Furnace Current with full charge	Coil voltage (for 184 amperes)	Power Factor	Input kw.
Calculated	6200	300	735	6.5	23.8
Found	6100	184	740	10.7	14.5

is a water-cooled cylindrical shield formed by casting a shell of neat Portland cement around a helix of copper tubing. This shield supports the thermal insulation around the upper end of the furnace chamber and protects the micarta casing of the furnace against heat from the charge. The top end-plate is provided with an opening through which the furnace is filled. When the furnace is in operation, this opening is closed with a water-cooled cover provided with a glass observation window. A rubber gasket and stopcock grease form a vacuum tight joint between the cover and the end plate.

The melting chamber is formed by placing a crucible within the coil and inverting a second one over it. A hole is cut through the bottom of the second crucible to allow for charging and for observation of the occurrences within. Zirconium silicate, ground to a uniform size of approximately 100 mesh, has been found a very satisfactory material for providing the necessary refractory thermal insulation around the furnace chamber. All the space between the crucibles and the coil and thermal shield is packed with this material, and the furnace is then ready for charging. The whole volume of the melting chamber is available for containing the ingredients of the charge because as melting proceeds in the bottom crucible fresh material settles down from the top.

With the furnace charged and the cover in place, evacuation is next in order. We have used No. 2 Trimount rotary oil pumps, exhausting into a system whose pressure is kept at approximately ½ inch (10-12 mm.) of mercury by a reciprocating vacuum pump. When the furnace is cold, the pressure within it can be reduced to a few hundredths of a millimeter of mercury, but it is usually impossible to get much below five millimeters of mercury when the furnace contains a molten 50-pound charge of iron, for example, be-

cause of the evolution of gases from the charge and the hot refractories.

With the furnace exhausted and water flowing through the coils, it is ready for operation. It is connected to the bus-bars and the alternator is started and

TABLE V.

Log of High Frequency Vacuum Furnace Operation
Charge: 50 lb. 4 per cent Silicon-Iron Alloy

Time Mins.	Current	Voltage	Frequency cycles/second	Vacuum mm. Hg.	Remarks
0	0	0	....	0.5	Power on.
10	100	....	8000	....	Top half of coil.
20	150	500	8500	....	
30	175	600	9000	2.5	
50	80	500	10500	2.5	
65	140	750	→7000	30.	Changed to full coil.
75	180	1000	7400	20.	Melting evident.
90	192	1100	....	....	Melting complete.
130	210—180	Off scale	....	....	
150	200	Off scale	....	22.	
155	→100	....	....	....	
165	→ 50	....	....	15.	Freezing commences.
170	→ 0	....	....	....	Top solid, power off.
410				3.	Furnace opened.

allowed to speed up with small field excitation. At first the current is imperceptible but it soon rises sharply to a maximum as the resonant frequency is passed. When the resonant frequency has been found, the alternator speed is reduced to give a slightly lower frequency and the field excitation adjusted to give the desired furnace current. Stable operating conditions

To H₂ Supply

100 Mesh Zircon

Top Level for full charge when Molten

Coil·50 turns ⅜" O.D. (1.90 cm.) x ½" I.D. (1.27 cm.) cop. tube Flatten to 0.45" tk. (1.14 cm.) Wound on Edge

Asbestos Rings

Zircon Crucibles

Lock

Axis of Rotation

Micarta Tubing

Asbestos Abutments

Structual Iron Frame on Rollers
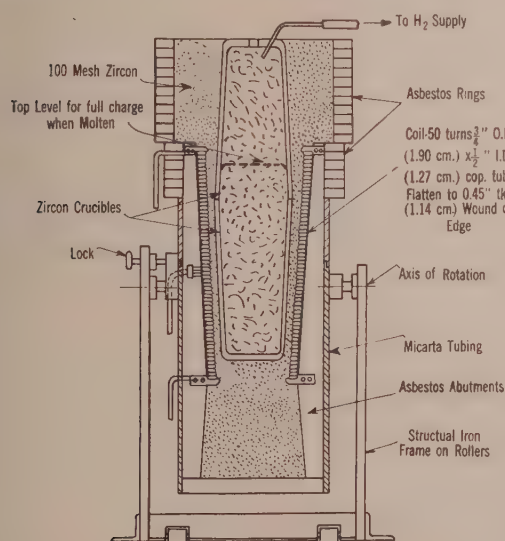
Fig. 8

are obtained by working slightly below resonance because tendency to increasing speed is counteracted by the increased load on the generator due to increases in both furnace current and power factor at the generator terminals which take place as resonance is approached.

After the melt has been brought to the proper condition, it is cooled by decreasing the power input and bringing the temperature of the charge down until it is close to the solidification point, and then cutting off the power, allowing it to freeze. The cooling schedule has an important bearing on the soundness of the ingot and is determined by experience. By using only the top half of the coil during cooling, the solidification of the top of the ingot can be retarded. This practise aids considerably in getting ingots which are free from shrinkage cavities.

The log of a typical run of one of these vacuum furnaces is given in Table V.
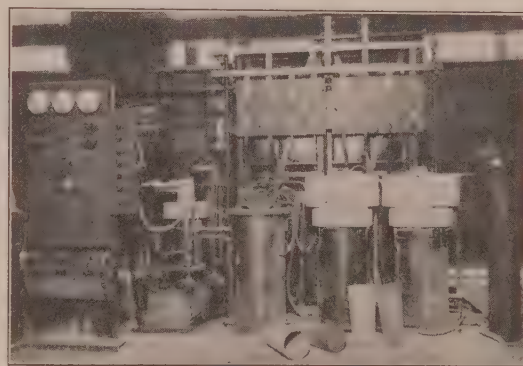
FIG. 9—HIGH FREQUENCY FURNACES, 225-LB. (100 KG.) CAPACITY. HIGH FREQUENCY MOTOR-GENERATOR SET AND CONDENSER BANK IN BACKGROUND

The variations in the frequency are due to the changes in the inductance of the furnace caused by the changes in the coupling coefficient and the resistance of the charge which occur as the latter is converted from a stack of irregularly shaped pieces of metal to a cylindrical molten mass.

When the ingot has cooled sufficiently, the vacuum is released, the zircon scooped out and the crucibles and

FIG. 10—HIGH FREQUENCY FURNACES. FROM LEFT TO RIGHT; CONTROL PANEL, VACUUM PUMP, 50-LB. VACUUM FURNACE, TWO 225-LB. (100 KG.) FURNACES, HYDROGEN TANK. CRUCIBLES AND INGOTS IN THE FOREGROUND

contents lifted out with a pair of specially designed tongs. The taper of the furnace coil facilitates removal of the charge.

The bottom crucible is used but once, but the top one usually lasts through five or six heats. The zircon is used repeatedly although there is some loss due to its

caking on the outside of the lower crucible, and being discarded.

Fig. 8 is a diagrammatic cross section of a furnace designed to melt 225-lb. charges of iron. The general appearance of some furnaces of this type is shown in Fig. 9. They are carried by structural iron frames mounted on rollers so that they may be easily moved about, and trunnions are provided so that they can be tilted for discharging. The melting chamber is formed by two crucibles, one inverted above the other as in the vacuum furnace. The hydrogen, or other protecting gas, is led in through a small side opening near the top end of the upper crucible. Zirconium silicate is packed between crucibles and coil and rings of asbestos lumber retain it around the upper crucible, above the end of the coil.

The necessity for using copper tubing of such large radial width may be questioned, but experience with some of the first furnaces built shows that the inductor coil must possess considerable mechanical strength if it is to resist the stresses caused by the expansion of the crucible. The zircon packing between the crucible and

type, shown diagrammatically in Fig. 8. The one next to the vacuum furnace was in operation when the photograph was taken. In the foreground are two ingots from the large furnaces and two of the crucibles used to make them.

In the early stages of our high-frequency furnace work the problem of refractory thermal insulation and of crucibles and furnace linings gave us much concern. Zirconium silicate is now used almost exclusively for thermal insulation, and the same material bonded with a small percentage of refractory clay is used to make furnace linings and crucibles. The process for making these crucibles was worked out by A. A. Frey, of the Research Department of the Westinghouse Electric & Manufacturing Company, and the crucibles are now being manufactured regularly at a cost which makes it economical to allow the ingots to solidify in the crucibles and use the crucibles but once. Thus, we avoid the pouring of ingots and the attendant complication and expense, eliminating the need for skilled personnel which would otherwise be required for this work.

Because of the unusual character of some of the

TABLE VI.
Log of Run of 225-lb. High-Frequency Furnace Charge: 225-lb. Iron-Nickel Alloy

| Time in Mins. | Current in Furnace | Voltage | | Kw. Generator Output | Kw. Motor Input | Frequency | Remarks |
		Generator	Furnace				
0	280	252	1780	70.6	99	4650	Start 80 lb. metal in furnace
10	400	256	2330	102.5	146.5	4650	
20	400	232	2260	93.0	135.0	4800	150 lb. of metal in furnace
30	400	232	2120	93.0	115.0	5000	
40	400	210	2030	84.0	104.8	5200	Charging completed
50	250	180	1250	45.0	60.0	....	Melting completed
60	250	87	1020	21.6	48.6	4700	Cooling started
70	205	71	800	14.5	42.0	4700	
80	205	70	805	14.3	42.0	4700	Top frozen
85	205	70	805	14.3	42.0	4700	
90	0	0	0	0	0	....	Power off

coil does not seem to possess a great deal of resilience, and water leaks in two coils were definitely traced to stretching due to the thermal expansion of the crucible and refractory packing.

The operating routine of these furnaces is not greatly different from that of the vacuum furnace just described. Melting is done at atmospheric pressure, usually under the protection of a suitable gas. Hydrogen is convenient and has been used in the majority of cases. The gas is supplied from a tank of compressed gas through a regulating valve. A typical log of a furnace run on a 225-lb. charge of iron-nickel alloy is shown by Table VI.

Fig. 10 gives a good idea of the general appearance of a portion of the melting floor as seen when looking toward the control panel and high-frequency motor-generator set. In the center is seen one of the vacuum furnaces described above, and between it and the control panel may be seen the vacuum piping and the oil pump. The mercury manometer and vacuum connection to the furnace appear on the right side of the furnace. The two right hand furnaces are the 225-lb.

processes and much of the equipment used in this plant, it might appear that it is nothing more than an overgrown laboratory, burdened with all the complications and expense usually associated with laboratory operations. A laboratory might be defined as a place where results are obtained without regard to cost or output,

TABLE VII.
Analysis of Production Costs based on Monthly Output of 30,000 lb. (13,500 kg.) (Costs in cents per pound)

	Electrolytic Iron	Iron-Nickel Alloy (ingots)
Labor	1.96	1.51
Incidental factory expense	10.36	6.81
Material	4.23	28.3
Totals	16.55	36.62

while the plant must produce the same results without regard to anything but cost and output.

When the plant is operating on a production schedule, there is one furnace connected to the power supply at all times, while others are being charged or emptied. The maximum output which has been required in any

one month was slightly more than 30,000 pounds, and this figure was reached without difficulty.

The operations of this plant have been subject to the same cost analysis and accounting procedure as other works departments of the Westinghouse Electric & Manufacturing Company, and the figures given by Table VII are believed to be trustworthy. The item "Incidental Factory Expense" covers capital charges, amortization, rental, supervision and all other overhead charges.

These figures are very satisfactory for they indicate that, by the extension of laboratory methods, it has been possible to produce a highly specialized material of great purity which meets very stringent specifications, at a cost not far different from the market price of ordinary commercial material having the same nominal composition but very much inferior properties.

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Discussion at Midwinter Convention

A NEW ALTERNATING-CURRENT GENERAL-PURPOSE MOTOR[1]
(WEICHSEL)
NEW YORK, N. Y., FEBRUARY 9, 1925

C. F. Scott: It happened to be my lot to be associated with Mr. Tesla in his early work in the development of his polyphase motor. I remember very well his statement that his motors were of two kinds: the synchronous motor, a splendid motor to run; and the induction motor, which he called a torque motor, that would start. The difficulty with the synchronous motor was first to get it started and second to excite it. The difficulty with the induction motor, primarily, was the lagging or magnetizing or exciting current which it required. That lagging current was a mysterious sort of thing; it was the practise to attribute anything we didn't understand in those early days to "lag."

A recent letter from Mr. Weichsel said that a score of years ago, when we were together in the Westinghouse Company in Pittsburgh, he attended one of the lectures that I gave to the students and remembered how I used yellow chalk horizontally for one kind of current and red chalk vertically for the other kind, and it gave him a clearness of conception of what was going on in circuits and an interest in it which continued. So maybe I can claim a sort of fatherly connection to the new motor, which is really a combination in one structure of those early beginnings which Tesla described as the torque motor and the synchronous motor.

The new motor has some rather striking and commendable features. The general simplicity is notable. The motor combines the starting characteristics of the induction motor and the running characteristics of the synchronous motor. It is two motors in one. It is self-contained; it has no outside exciter. There is an automatic transfer from one function ot the other, without any action of the attendant. It is simple in construction, with very simple additions or modifications to the regular induction motor.

In its construction, in its auxiliaries, in its operation, it is a simple and admirable machine, and to those of us who, back before these things were evolved, have contemplated the difficulties in the problem, and the great desideratum in getting a combination of these two motors in one simple arrangement, this solution is a most delightful one. From the engineering, inventive standpoint, it is a fine thing. And, to get a performance which is substantially that of the induction motor and of the synchronous motor, with some advantages in connection with each, is a splendid result.

W. L. Upson: This paper is a discussion of the design and operating characteristics of the now well-known Fynn-Weichsel motor and does not particularly go into the question of the demands for a power-factor-correcting motor. This latter subject has been quite fully discussed elsewhere. Fortunately this motor has now been in service long enough to establish its ability to do what is claimed for it and to demonstrate that what might seem like complications of structure are really of insignificant importance. Certainly any quantity of electrical apparatus containing as many or more complicated features is in constant use and accepted without question in practise. However, it is of interest to note that of these so-called complications the commutator, for instance, is actually much less of a problem in this motor than it is in other machines in general.

To my mind, by far the most interesting feature of the design of this motor is its small air-gap: a synchronous motor with an induction-motor air-gap. For some years I have been an advocate of smaller gaps and have felt that it was possible for the designer to obtain substantial advantages by working in this direction. In this connection I wish to quote from a discussion by Mr. H. M. Hobart contained in the TRANSACTIONS of the Institute, Vol. XXXII, p. 1595, 1913.

"Any proposition to consider the design of synchronous motors along the lines of the design of induction motors has always been handicapped by the necessity of a change of hands, as to who should design it, and bring about the evolution of the synchronous motor into a decent machine. It is at present an absurd caricature of what it might be .... I believe that the synchronous motor can be used to great advantage in much smaller sizes than has heretofore been considered desirable, in sizes which will lap over into the field that has been generally held by common consent to belong to the induction motor. If only the synchronous motor could be designed by induction-motor designers, working on the lines which have enabled them to see just what is needed for these starting and running-up conditions, the result would be for the good," and Mr. F. D. Newberry, taking part in the same discussion, admits the unsatisfactory development of the synchronous motor but imputes it to "the difference in the magnetizing current required by a well designed induction motor and a well designed synchronous motor."

It is true that a salient-pole synchronous motor would have an advantage over one with a round-rotor field providing both had the same air-gaps and both were of standard design, but in this new motor we have the restricted gap which, apparently for the first time, fulfils the desire expressed by Mr. Hobart, and in addition we have a self-exciting feature which practically over-

comes the disadvantages usually encountered due to armature reaction. It would therefore seem highly desirable if we could have a comparative study of a Fynn-Weichsel motor and a standard salient-pole synchronous motor. The former exhibits such remarkable synchronizing power that it would appear that this feature might be made the basis of such a comparative study. It would be interesting to compare these motors on the basis of weight for equal capacities. On the basis of efficiency, the Fynn-Weichsel motor has every advantage, even that of commutator losses, if we take into consideration, as we should, the source of d-c. supply required by the standard synchronous motor.

There is one other feature I should like to mention, and that is that this motor requires a somewhat longer shaft between bearings than do other motors, and with the small gap, this becomes a feature in the mechanical design of considerable importance. The rotor must be truely centered, the shaft must be stiff and the bearings must not be subject to wear. These conditions might naturally be expected to add somewhat to the cost of the motor. However, there seems to be no good reason why they should not be met.

R. E. Ferris: With the operating men with whom I have talked, the cost of maintenance and continuity of service is a very important factor, of first importance, you might say. Therefore, it seems to me that all complications possible should be omitted, even at the expense of slightly reduced desirable operating characteristics.

There is one thing that has been introduced in this motor, and that is a double winding. As a d-c. designer, I have tried to avoid double windings consistently. When we got into the higher voltages, we were almost of necessity driven to double windings, especially on machines of lower capacity. However, I have even gone to the extent of designing two separate armatures, separating the commutators, and in that way the windings, in order to avoid, what seemed to me, the complication of a double winding.

L. M. Perkins: The Fynn-Weichsel motor or any high-power power-factor motor must cost more than a simple induction motor. It cannot be made to cost less, because it is exactly like the induction motor, with the addition of a commutator and extra brushes and winding.

The higher energy cost is inherent in the high-power-factor motor. If the motor has a high power factor, it means that the secondary current is thrown out of phase, very decidedly, with the field flux of the motor and, therefore, the torque for a given current and a given field is markedly decreased. The higher the power factor, the more this torque will be decreased. In addition to this, of course, there are the commutator and brush losses which again decrease the efficiency.

In his paper, Mr. Weichsel brings up a comparison of efficiencies or copper losses of the Fynn-Weichsel motor as against the plain induction motor. This appears in Fig. 24. While D is the primary current of the ordinary motor and C is the primary current of the Fynn-Weichsel motor, D is the current which flows in the stator winding and, therefore, the large winding of the normal motor, while C is the current which flows in the rotor winding or small winding of the Fynn-Weichsel motor. On the other hand, B is the current which flows in the rotor winding of the ordinary motor, while A is the current which flows in the stator winding of the Fynn-Weichsel. Therefore, A and D should be compared while C and B are also compared. C and B cannot differ very much, but A is much larger than D, and therefore entails much higher loss.

In addition to that, the point made about the concentric winding used in the stator of the Fynn-Weichsel motor can also be applied, of course, to the induction motor which can also use a concentric winding.

Further than this, the examples chosen, comparing the Fynn-Weichsel motor with the synchronous condenser, are not the most practical conditions because the Fynn-Weichsel is, in general, built in smaller sizes, and in those smaller sizes the commercial comparison will be made not between the Fynn-Weichsel and the synchronous condenser, but between the Fynn-Weichsel and the static condenser which has very low losses. For this reason, the Fynn-Weichsel motor cannot have a greater loss than the equivalent induction motor, without suffering a loss of efficiency of the system.

W. C. Kalb: In considering a motor of the type described by Mr. Weichsel there is one factor which should not be lost sight of, and that is the peculiarity of the operating characteristics of the motor when meeting overload conditions. On certain applications this represents a distinct advantage and may give the motor a preference over other types.

As a specific case, I have in mind a certain mill where it is essential that a product be ground to uniform mesh. The objection to an induction motor is that this apparatus is operated by unskilled labor, incapable of judging its operation by watching any form of indicating meter, and that the fineness of the material produced varies with the speed. As the mill becomes overloaded by too rapid feeding on the part of the operator, the drop in speed is gradual; it does not call itself to the attention of the operator by a change in tone, and variation in mesh results. The synchronous motor would be ideal from the standpoint of uniform speed, but the objection to it is that when the overload point is reached, the motor drops its load and the material circulating through the separating system drops back into the mill, stalling it completely, and making it necessary to open the mill and remove the charge.

With the peculiar characteristics of the Fynn-Weichsel motor, when this overload condition is reached the motor drops into induction operation at a sufficiently rapid rate so that the change in tone of the mill is noticeable. The operator at once recognizes that his machine is overloaded, ceases feeding until it has time to clear the load, and then proceeds without interruption and with but a momentary disturbance of the uniformity of his product.

F. G. Baum: The operating men and the designing engineers know that the induction motor as it is today and will probably continue for a long time is what might be called "the brute of the electrical system." That is, the induction motor not only throws on the kilowatt-hour load, but throws onto the system a kv-a. load which pulls down the voltage of the system. That burden that it throws onto the system, let us say, by making a power factor 0.80 in place of 1.00, may increase the current 25 per cent, which may increase the losses, say, 50 per cent in our transformers, in our transmission and in our generators. We have then to take account of the losses all the way through to the power station.

In the design of the generators, the worst thing that the generator designers have had to contend with in the last twenty-five years has been this question of the power factor. Low power factor not only adds a burden all the way through but we must carry probably 50 per cent higher excitation on the generators than we would for unity power factor. For example, we may have the generators excited for 100 amperes at open-circuit voltage, 200 amperes for unity power factor, and 300 amperes for power factor of 0.80. The high field called for by the low power factor is a menace to the system and it is, you might say, a pointed gun presented to cause trouble in case anything happens.

Anything that will tend to correct that, of course, will be beneficial. I have for years been hopeful that the synchronous-motor designers would design small units, and I believe they are doing that more and more. I think we are going to see more of that done in the future, for I believe we would have an entirely different kind of power system if we could get rid of this "brute" action of the induction motor on the power system. Such work as Fynn and Weichsel are doing is therefore of general interest to the electric power industry.

R. E. Doherty: I think there is no question whatever that

in those cases of application in practise where the particular characteristics which these motors have are required and where the economics of the situation justify the investment, they have a real field. Those facts will determine, of course, the extent of the application.

With reference to the historical sketches of Professor Upson, which I believe dated back to 1913, I would call attention to the fact that very material progress has been made in the design of synchronous motors since that date. Whether in the future the synchronous motor is going to be further developed and this question of power factor solved by a simplified synchronous motor, or whether it is going to be solved by some form of commutator motor, will depend altogether upon the economic factors in the situation and the requirements of the loads.

A. M. MacCutcheon: I would like to ask Mr. Weichsel how the resistance is automatically cut out in starting this motor.

It seems to me that this type of motor surely has its place. I think Mr. Weichsel said that the cost of the motor was some 15 per cent, on the average, over that of a slip-ring motor of equal capacity. We all appreciate the increase in the price of a slip-ring motor over the very simple squirrel-cage. We appreciate that there are some disadvantages to the commutator, and to the extra windings. As a previous commentor has said, we must equate between the additional cost and the additional advantages. I suggest as a new idea that if we are going to go to the commutator, possibly we can correct the power factor either by a large size motor of this type or by a synchronous motor, if that is more economical, driving a direct-current generator and have a certain number of direct-current motors in a plant with all their consequent advantages.

Some eight years ago I think a good many felt that the day of the direct-current motor had passed. If I interpret the tendency in the commercial field today aright, there is a very decided tendency to use both alternating and direct current in any large plant as the ideal system. There are still many things that can be done with the direct-current motor which cannot be done with the very excellent Fynn-Weichsel motor. Therefore, if we increase the power factor by some form of large unit, either a Fynn-Weichsel motor or a synchronous motor, which could be easily maintained and inspected, it might be more economical than a large number of Fynn-Weichsel motors distributed throughout the plant, and we would have direct-current as well, with its very obvious advantages.

C. F. Scott: I don't know that we all recognize the fundamental basis of this discussion on motors. It happens that Faraday and Henry when they invented electromagnetic induction put in two things: motion, and magnetic field. Those two things—the motion and the field—for producing electromotive force are the fundamentals of our electromagnetic machinery. Without the field, a generator or a motor is helpless.

We have been much troubled about the field. Alternators have exciters as a matter of course. The motor, too, must have its field and the question is: Can we produce that field more economically locally at the motor by having permanent magnets, by providing direct current for excitation from a battery or an exciter, or can we bring the exciting current in the form of alternating current (lagging or "wattless") from our alternator which supplies the in-phase power current? If we take magnetization for the motor from the alternator, we subtract from its magnetization and we must, as Mr. Baum says, put more d-c. excitation into the generator. We must produce somewhere the excitation for every machine in the system. One way is to produce all the excitation (as well as all the "motion") back in the power-house by putting in a bigger exciter and supplying magnetizing current through alternating mains. Another way is that of the motors described today, in which the commutator makes the motor self-exciting.

We are content to supply the motion, the power, the turbine, but everybody thinks it is all wrong that we should have to supply the magnetization. If Faraday and Henry had done differently we might do differently too, but as things stand we must supply both.

C. H. Sonntag: The Portland cement industry, with which the writer is identified, is one of those in which efficiency and high power factor in power transmission have been somewhat sacrificed to secure the greatest possible continuity of mill operation. This is particularly true in the case of the smaller motors. The tendency in recent years towards larger grinding machines has carried with it the demand for larger motors, which for application to individual machines now range in size from 75 h. p. to 500 h. p. Of these, the smaller ones are of the slow-speed squirrel-cage type, usually running at about 500 rev. per min. and so having only a moderately high power factor, while the large motors are usually of the synchronous type, which can be operated with leading current.

If these were the only motors to be run, the power factor of the system could be kept at a very satisfactory point. Unfortunately a cement mill needs a large number of small motors to drive conveyors, elevators, packers, kilns and other necessary machines. These motors will range in size from 5 to 25 h. p. or more, and to avoid excessive speed reduction, will run at a moderate speed—say about 700 rev. per. min.

The effect of these small slow-speed motors on the system power factor would be bad enough, even if they were fully loaded. But the cement-mill operator has learned from experience that such drives are frequently heavily over-loaded, due to slides of cement, accidental or necessary stoppages, and the general tendency of unskilled help to overload equipment. It is a peculiar fact that a screw conveyor handling cement, ground limestone or similar material will carry a very large load without excessive power demand as long as the material is kept moving, for the air that is mixed with the powder makes it almost as mobile as a liquid. But if the loaded conveyor is stopped for a few minutes, so that the contents have a chance to settle and pack, it will be found impossible to start it, if of any length, with a motor that is only large enough to run it as long as it is in motion. Such drives are usually over-motored at least 50 per cent, sometimes more, and the effect on the power factor can be imagined.

The cement manufacturer would welcome some way to correct for the low power factor of these small drives, and this way is now offered through the use of the Fynn-Weichsel motor that has just been described. What is needed is a machine that is reasonably simple so that the brutal treatment it will receive, and the constant presence of cement dust in the air will not put it out of business, and that does not require separate excitation. The Fynn-Weichsel motor is, in the writer's opinion, such a machine.

Some may think that the presence of a commutator makes this motor undesirable for use in dusty places. So far as the dusts found in cement-mill practise are concerned, this conclusion is not borne out by the facts. The commutator, instead of being cut and scored away by the dust, is given a high polish, and stays in excellent condition. When electric drive was first introduced into cement-mill practise, it was by the use of direct-current motors, and the excellent records made by the commutators of these old machines are still a matter of comment by those who were familiar with them.

Recently the writer had an opportunity to made a complete graphic record of the performance of one of the department circuits of a cement mill, on which were four 25-h. p., 1200 rev. per min., Fynn-Weichsel motors, together with seventeen squirrel-cage motors ranging in size from 50 to 5 h. p., most of them only half-loaded, and running at 690 rev. per min. The circuit was at 440 volts, three phase, 60 cycles. The Fynn-Weichsel motors were each driving, by direct connection through a flexible coupling, a three-tube Bates packer, which is a machine for filling bulk cement into bags. The average load on each was about 20 h. p. The other

motors were driving screw conveyors, elevators, dust-collecting fans and a bag-cleaning wheel.

The sections of simultaneous charts from the graphic watt-meter and power factor meter shown herewith in Figs. 1 and 2 give a very good idea of the influence of the Fynn-Weichsel motors on the power factor of the circuit. The entire record is too long to show satisfactorily, so only the important parts are exhibited. The curves are somewhat irregular, because the entire equipment was working under commercial rather than laboratory conditions.

A number of squirrel-cage motors were started in order to get enough current through the power-factor meter to insure positive operation. The first was a 50-h. p. fan motor, partly loaded with a power factor of about 62 per cent. As smaller lightly loaded motors were started, the curves show very plainly that while the

Some of these are not needed continuously, and the effect of shutting them down is shown in Fig. 2.

At *P* a 10-h. p. squirrel-cage motor is shut down. The power falls to 118 kw. and the power factor rises to 88 per cent.

At *Q* another 10-h. p. squirrel-cage motor is stopped, the energy dropped to 110 kw., and the power factor rising to 94 per cent.

At *R* and *S* stopping two 20-h. p. and two 10-h. p. squirrel-cage motors drops the power to 63 kw. and raises the power factor to 84 per cent *leading*. At this point four Fynn-Weichsel motors and a few small ones were still running, but the load on the Fynn-Weichsel motors was falling off.

At *T* a Fynn-Weichsel motor was stopped and the power dropped to 55 kw., the power factor changing also to 88 per cent leading.
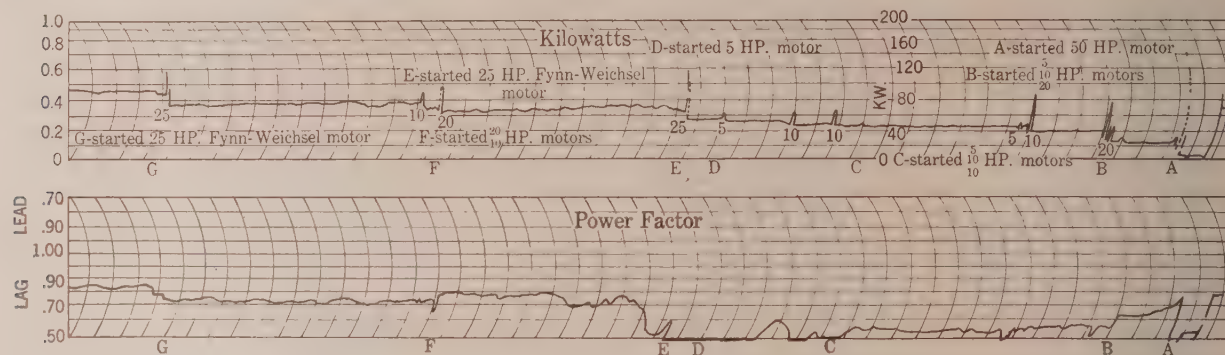
Fig. 1
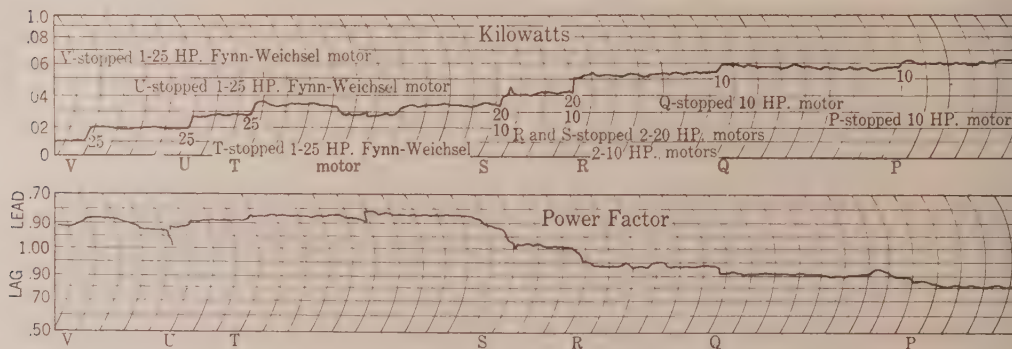
Fig. 2

FIGS. 1 AND 2—LOAD AND POWER FACTOR CHARTS OF MILL HAVING FYNN-WEICHSEL AND SQUIRREL-CAGE MOTORS

power demand increased, the power factor went progressively down until it went below 50 per cent, which was as low as the meter would register. The pen was against the stop when it drew the straight line at the point *D*. The indications on the wattmeter charge should be multiplied by 200 to get correct values.

At *E* the first Fynn-Weichsel motor was started, and the immediate increase in power factor from less than 50 per cent to about 78 per cent is very evident.

At *F* more small motors were started, bringing the load to 78 kw. and the power factor to 72 per cent.

At *G* another Fynn-Weichsel motor was started, bringing the power to 96 kw. the power factor to 83 per cent.

The load was further increased by adding two more Fynn-Weichsel motors and three small ones, with a final load of 125 kw. and a power factor of 83 per cent, which is excellent considering the underloaded condition of most of the small motors.

At *U* another Fynn-Weichsel motor was stopped, power falling to 39 kw. and power factor to 95 per cent leading.

Beyond this point the indications of the power-factor meter were not dependable, owing to the small current flowing in it. Taken in their entirety these charts show that the Fynn-Weichsel motor is of very real value in counteracting the poor power factor of underloaded slow-speed induction motors. Where conditions permit, this correction may be carried to the point where the resultant power factor makes the load a desirable one either for the central station or the isolated plant.

P. H. Thomas: While there can hardly be much new to be said at the present time on the subject of power-factor correction in industrial power-supply circuits, it still may be worth while to point out the fact that the indicated development of our power-supply systems is likely to throw a somewhat different emphasis on the importance of lagging current.

It goes without saying that considering the field in general,

each actual situation must be considered by itself and they range all the way from conditions where power-factor correction is of no value to those in which power-factor correction is all-important.

Where the effect of lagging current is merely to lower the power factor of the load of a generator, leaving it still well within the proper operating range of the generator and where regulation and losses on transmission lines are not deleteriously affected, there is very little warrant for the additional expense or the lower efficiency of special forms of induction motors. This is because the use of such motors will not reduce the initial cost of the system or its operating expense. In cases, however, where the amount of lagging current is sufficient to load the generators beyond the safe current-carrying capacity of armature windings, or where the regulation is adversely affected, or in those cases where the local feeder voltage drop or line losses become excessive, power-factor correction at the load end of the feeders becomes worth while, but there is always a question as to the best method of making the correction. The type of motor advocated by Mr. Weichsel will admirably meet many cases; sometimes the power factor may be better corrected through large synchronous motors. In this case the additional cost of the special apparatus must be balanced against any saving that can be made in the necessary correction in generators and feeders.

In those cases in which this correction must be made by installing additional apparatus, such for example, as additional generators or synchronous condensers or their equivalent, the advantage of using motors of the type proposed by Mr. Weichsel becomes very greatly enhanced, for the installation of new capacity in generating apparatus or condensers is a very different thing from operating existing machinery at a lower power factor. In other words, up to a certain point there is very little to be gained by the more expensive, higher-power-factor motor and other expedients may be cheaper; beyond this point the importance of the high-power-factor motor may become emphasized many times over; other remedies then become very expensive.

I would like to point out further that as interconnection and interchange of load forward and backwards between power systems grow, the situation is likely to call for high-power-factor load with considerable emphasis. To pass power forward and backward over the same line there must be a control of the power factor and if this power for both ways is anything like equal in volume it will be necessary to have it pass at leading power in one or both directions. Obviously this condition of leading power factor can be obtained only by providing means locally for carrying all of the lagging current of the local load and in addition supplying whatever additional leading current may be required. In this case the expense of bad power factor is very great because it must be corrected by carrying the lagging current on rotating machines, at the same time carrying the load received over the interconnecting line.

As it is not possible to read the future of any particular system very far ahead, it may well be the part of wisdom to establish the policy of improving power factor of the general load from time to time as far as may be reasonable so that when the time comes when the high power factor is essential it will not be unduly expensive to secure it.

This brings forward another aspect of this matter. Since it is equitable and necessary that the purchasers of power shall ultimately pay the entire cost of furnishing the power plus a proper return on the investment and since bad power factor tends, in such cases as I have outlined, to increase very materially the cost of installation and to jeopardize the character of the service, there should be a premium in some form on a high power factor for consumers. At the present time in most cases while it is for the interest of the industry as a whole and the users in the aggregate that a good power factor should be established on a system, it is not to the interest of any individual consumer of power to have a high-power-factor load for it costs more money for him to get it and his individual bad power factor will not effect the cost of

power as a whole enough to effect his rate. In other words if he establishes a high power factor he will make a benefit to the industry in general but will not improve his own rate for power. If these rates be so adjusted, as they are in some places, as to make a saving for individual consumers to establish high power factors, the burden of producing this general high-power-factor condition, which is good for the general industry, will be distributed over all the consumers of power in a more or less fair proportion. It seems to me that this is perhaps the most important aspect in the present discussion of the power factor.

G. S. Smith: The paper presented by Mr. Weichsel gives a very thorough and enlightening analysis of this new development in the line of motors. However, like most new developments, it may require some education on the part of the buying public as well as an added incentive from the power companies, before its true worth is realized.

It is needless to say that most plants using electric power are over-motored though not always without good reasons. However, there is a strong tendency for the superintendent in charge to favor a much larger motor than necessary, to avoid operating troubles, since the motor often gets less attention than the remainder of the machinery. Outside of the added investment in the first cost of the motor the power consumer is suffering no great loss unless he is penalized for the resulting poor power factor.

Since over-motoring a plant is often desirable, if not necessary, there is little doubt but that the future will see a great need for more power-factor correction, and this motor ought to supply that need since it has many desirable characteristics together with all the ease of starting found in any wound-rotor induction motor.

A series of demonstration tests were run on a 15-h. p. motor at the University of Washington, and the operation of the motor was found excellent. Its various characteristics were checked, and a number of oscillograms taken showing starting as well as various changes in operation from synchronous to induction operation and the reverse. The ease with which it synchronized even at high overloads, due to the so-called injected current, seemed the most remarkable part.

It might be desirable to afford some means of easily adjusting the power factor at which the machine operates after it is installed. Such an adjustment should be simple, though it might not be justified since every added adjustment usually means an added possibility for trouble.

There seems to be a decided fluctuation in the a-c. current drawn by the machine when it changes to induction-motor operation on overload. This, of course, is to be expected after the function of the injected current due to slip is understood, though it is not altogether desirable. The oscillogram in Fig. 3 herewith, shows this current variation and its relation to the induced currents in the two stator fields. The fluctuation indicated on the oscillogram is probably greater than would ordinarily take place since the change in load was made quickly in order to reduce the time and obtain a good record of the values both before and after the change. This doubtless resulted in some hunting of the larger machine used as load. However, the load at which it drops out of step is so high that it would seldom operate thus.

Inquiries have been made by engineers in this territory as to its operation as a generator when driving torque is applied to its shaft. It might thus be used to develop small water-power cities, floating on the line at periods of low water, and run as a self-excited alternator when water is available. Its power factor for both periods could probably be kept near to unity, or leading.

Some tests were run on a 7½-h. p. machine with the d-c. brush setting specified by the factory for motor operation. It was found that at small loads the machine would generate as a self-excited alternator but would soon drop out of step and operate as an induction generator with similar slip characteristics as given on motor operation at overload. Fig. 4 shows an oscillogram of

various currents and voltages in the machine with this operation and may be of interest.

Tests were also made with several other d-c. brush settings, and with positions near 90 electrical degrees from the field axis, the machine would easily carry full load at synchronous speed, with a leading power factor, approaching unity as the load increased. At higher loads the machine dropped out of synchronism and continued as an induction generator but readily dropped back into step at about the same load it carried before when running at synchronous speed. The field current was slightly higher than for the same load on motor operation, but remained at about the same value throughout the range of load.

Fig. 5 shows an oscillogram of its performance changing from synchronous-generator to synchronous-motor operation near half load on each. The brush setting for this was about 67 electrical degrees from neutral in the direction of rotation. There is

still very good, even though it was belted to a much larger machine.

From the educational point of view we have taken a great deal of interest in this machine since it is very illustrative of the possibilities of new developments by combination of the characteristics of well-known machines. We are interested in seeing the most made of its possibilities, as well as in the elimination of its disadvantages. It seems to be a big step forward toward supplying an increasing need which is not now satisfied.

C. R. Underhill (Communicated after adjournment): I regard this motor as a very important and timely device. Power-factor correction is an economic and operation proposition, and where motors having the general characteristics of the one described can be applied to an existing industrial-plant distribution system, particularly when placed close to motors whose power factors are to corrected, such motors should undoubt-
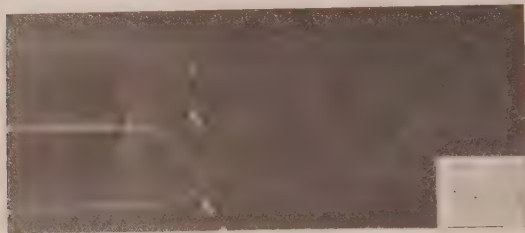
Fig. 3

Fig. 4

Fig. 5
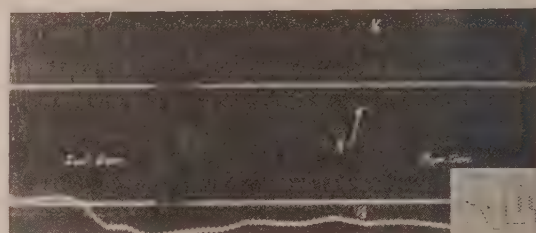
Fig. 6

FIGS. 3-4-5 AND 6—OSCILLOGRAMS SHOWING OPERATION OF FYNN-WEICHSEL MOTORS UNDER VARIOUS CONDITIONS

Figs. 4-5 and 6 are for a 7½ h. p.-motor

Fig. 3 is a 15-h. p., 220-volt motor dropping out of synchronism. V_1 is line current. It was 50 amperes before the motor dropped out of synchronism and 80 amperes afterward. V_2 is current in the auxiliary winding, and it was 41 amperes before dropping out of synchronism. V_3 is current in the field winding. The power factor was 0.81 leading before dropping out of synchronism and 0.72 lagging afterward.

Fig. 4 shows the change from motor to induction-generator operation. V_1 is line current. V_2 is current in the auxiliary winding. V_3 is field winding current.

Fig. 5 shows the change from synchronous-generator to synchronous-motor operation. The generator load is 2.7 h. p.; the motor load is 4.3 h. p. V_3 the generator field amperes are 15; the motor field amperes are 19. V_2 equals auxiliary-winding amperes. V_1 equals lines amperes.

Fig. 6 shows the change from induction-generator to synchronous-generator operation. The synchronous generator load is 5.3 h. p. The synchronous-generator field amperes, V_3, equal 11. V_2 equals line voltage.

little change to be noticed except the phase difference of voltage and current. The oscillogram represents a little less than 0.5 sec. in time. The power factor was leading for both operations. Fig. 6 shows its performance as an induction generator pulling into step and continuing operation as a synchronous generator at the same brush setting as for Fig. 5. Here again the quick change required is responsible for a large part of the current variation. Oscillograms in Figs. 5 and 6 were taken on a 7½-h. p. motor, which is one of our laboratory machines.

Further tests were not made due to a lack of time, but, with the proper brush setting or some other adjustment, a generator operation might be found which is as desirable as its motor operation. The tests described simply show that it has possibilities as a generator.

It might be well to mention that at all brush positions tried, its starting and synchronizing characteristics as a motor were

edly be used. However, before deciding upon any form of power-factor-correcting apparatus, a careful study of conditions should be made, a change to a higher voltage considered, and then the induction motors should be loaded to their maximum safe capacities by proper substitution, that is, by putting the right motors on the right jobs, the diversity of operation being duly considered. I have supplied induction motors for new drives without purchasing a single motor, and have put a number of motors in stock besides, while increasing the plant power factor above the penalty limit by loading the motors to their proper capacities, and that is, or should be, common practise.

In considering the use of synchronous motors, static condensers, or motors of the type described in the paper, it must be remembered that a current of abnormal strength flows between the induction motor or motors and the power-factor-correcting device or devices. For instance, connecting a synchronous

motor or a static condenser across the plant terminals to correct the plant power factor does not remove the magnetizing current from the plant distribution system. Connecting static condensers across the terminals of individual induction motors minimizes the magnetizing current in the wiring system, but not in the conductors connecting a static condenser to a motor. Hence, the use of motors of the type described in the paper should be carried out with the full understanding that too great distances between induction motors and power-factor-correcting apparatus, or too small conductors, may be the cause of considerable losses in the connecting conductors.

Where two-charge rates prevail, for instance, control of the demand may be more important than correction of the power factor from a billing standpoint, and it is often difficult to impress upon plant managers the fact that further savings can be made after the demand has been minimized and the power factor raised above the penalty limit. Such managers have very poor conceptions of losses in their own plant conductors. They do not realize that higher voltages, or else larger conductors, would in many cases save them much money annually and pay good returns on the investment.

With the above reservations, I welcome the new motor, which I have studied and have witnessed in operation, as a general motor which, even if it has a commutator, is a distinct improvement over the present induction and synchronous motors. However, it should not be considered a cure-all, as in cases where plant conductors are too small or plant voltages are too low for the prevailing plant distribution system. There are instances within my own experience where there have been such excellent distribution systems and voltages that any savings in the distribution losses due to low power factor were not worth any expenditure for power-factor-corrective apparatus after the induction motors were fully loaded.

From my point of view, there is altogether too much stress placed on the efficiencies of motors. I prefer economy to efficiency. Would more efficient induction motors prove more economical if constructed from present available materials and and by present methods? I do not believe we could afford to buy much more efficient motors. From the industrial-plant manager's standpoint, the motor that will show the greatest saving in dollars is more important than the one that will show the greatest efficiency in per cent.

H. Weichsel: Professor Scott has presented, in a very vivid manner, the meaning of wattless and watt currents first by the "two-color" method which he devised years ago, and which has proven to be of an extraordinary help in explaining the more or less puzzling phenomena of watt and wattless currents, and second by the statement he made today that every electric motor requires excitation, which may either be produced in the power house or at its place of consumption. It may be expected that his manner of explaining these phenomena will greatly contribute to a clearer conception of the advisability and reasons for installing power factor correcting devices.

I agree fully with Professor Upson that from the electrical engineer's point of view an electric machine should have as small an air-gap as is mechanically possible. Professor Upson is entirely correct that the distance between bearing centers in the Fynn-Weichsel motor is larger than in standard induction motors. May I add, however, that the increase in length is not very large, as the width of the commutator is usually less than that of the slip-rings of a standard induction motor. Therefore, no abnormal problems arise in the design of the shaft for sufficient stiffness to prevent abnormal deflection.

Mr. Ferris stated that, in d-c. machines, he has found it usually disadvantageous to use double-winding armatures. May I point out that, according to my judgment, the problem in standard d-c. machines is quite different from the one which presents itself in the design of Fynn-Weichsel motors. In d-c. machines, especially in those machines to which Mr. Ferris refers, a high

voltage exists at the commutator and further, a high potential difference also exists between the two windings. In addition to the above, the energy carried by the commutators is quite appreciable.

On the other hand, in Fynn-Weichsel motors the voltage in the d-c. winding is extremely low and as there is no interconnection between the d-c. winding and the armature a-c. winding, no potential strain exists between these two windings. Further, the energy of the d-c. winding forms only a small percentage of the total output of the machine.

Finally, there is practically no possibility of a burnout of the d-c. winding on account of the peculiar characteristics of the exciting current of these machines. Tests, as well as theory, show that the exciting current between full load and maximum load varies only slightly.

Mr. Perkins points out that the copper losses in the stator member of a standard induction motor, when compared with the corresponding copper losses in the stator member of the Fynn-Weichsel motor, in his judgment, are materially larger for the Fynn-Weichsel motor than for the standard induction motor. This reasoning is based on the assumption that the concentric winding which is used in the Fynn-Weichsel motors can with equal advantage be used in standard induction motors. As I did not explain in detail the particular type of concentric winding which is used in Fynn-Weichsel motors, it can readily be seen why Mr. Perkins arrived at this conclusion.

The concentric winding, employed by me, cannot be recommended for standard induction motors, as it leads to uneven loading of the different phases. On the other hand, this winding is extremely advantageous in connection with Fynn-Weichsel motors, as it allows a better field distribution, shorter mean turn length, and a copper section in the axis of the main field winding which is larger than in the axis of the auxiliary winding. This results in a field winding loss materially below the values which Mr. Perkins estimated from the ratio of the vectors A and D in my Fig. 24. I may add here that this particular winding is covered by a United States patent.

Mr. Perkins further states that, in my paper, a comparison is made between an installation, the power factor of which is corrected by the Fynn-Weichsel motors and an installation with a power factor corrected by synchronous condensers. I am sorry that the paper conveyed this meaning to him. The paper makes repeated reference to "idle running phase-correcting devices," meaning thereby either static condensers or synchronous condensers. Static condensers, as a rule, require transformers and the energy consumption of these units or any other apparatus capable of producing leading wattless current without doing useful work amounts to about three to four kilowatts for every 100 kv-a. corrected. In Appendix 3, an example shows that, with power-factor conditions as usually found in praxis the efficiency of the Fynn-Weichsel motors can be 5.9 per cent less than that of a squirrel-cage motor and still give the installation the same overall efficiency as if it would consist of squirrel-cage motors only and the correction being produced by static condensers. Elsewhere in the paper it has been shown, however, that the efficiency difference between squirrel-cage and Fynn-Weichsel motors is considerably less than 5.9 per cent. Often these efficiencies are alike, while in large units they are even sometimes better for the Fynn-Weichsel motor than for the squirrel-cage motor.

Mr. Kalb mentions an experience with this new type of motor which is rather interesting. He states that the slight speed variation which occurs when these machines are sufficiently heavily overloaded to force them to operate as induction machines, has proven to be an advantage rather than a disadvantage. A condition similar to the one mentioned by Mr. Kalb has also been experienced in connection with protecting devices for these new motors. When the machines become sufficiently loaded to force them to operate as induction machines, the current draw from the line rises abruptly due to the change in power factor and to

the small speed variations. This, in some instances, has resulted in a very positive operation of the protective devices.

Mr. Baum stated in a very able manner the great difficulties and dangers which arise in a system with poor power factor, which usually is caused by "the brute, the induction motor." His warning that the excitation in the generators, due to low power factor, is a point gun, cannot be too much emphasized. According to present indications, Mr. Baum's hopes are soon to be ful-filled, as synchronous motors of small and medium sizes, es-pecially of the type described in the paper, are becoming more popular every day.

Mr. Doherty refers to the possibility of correcting the power factor by a variety of means. There is no doubt that it is an economic question to decide which method for correcting the power factor is the most advantageous. In my way of looking at it there is no universal remedy for the ills of poor power factor. There appears to be a field of usefulness for almost any of the known power-factor corrective means. It is an economic, as well as an engineering, problem to determine from case to case the best means for achieving the desired results.

Referring to Mr. McCutcheon's discussion, I desire to state that the starting resistances for this new type of machine can be operated automatically in exactly the same manner as for stand-ard slip-ring induction motors. He further points out the pos-sibility of achieving the desired results of power-factor correction by using d-c. distribution and a-c. transmission, employing a converter or motor generator set as a link between the transmis-sion and distribution systems. I believe that it will be found that such an arrangement is more expensive than a straight a-c. distribution and transmission system.

There is another point which should not be overlooked. In almost every industry there are certain places where nothing but squirrel-cage motors can be operated satisfactorily. Therefore, alternating current is required for these motors, and if direct current were to be used for the remaining machines, the wiring system would be unnecessarily complicated. For instance, this difficulty may be overcome by using straight a-c. distribution and correcting the power factor in the distribution system by using this new type of machine.

Mr. Sonntag contributed some very valuable information; his experience that the capacity of the squirrel-cage motors in cement mills must be selected in accordance with the starting torque rather than according to the running load, finds an analogy in a great many other industries. May I refer here, for instance, to the marble cutting plant which is discussed in the paper. By the use of Fynn-Weichsel motors, this difficulty is overcome and in a good many cases a smaller horse-power motor can be used. The advantageous results obtainable in this manner are very forcibly demonstrated by the charts he presents. His statement that cement dust is not detrimental to slip-rings and commutators appears to me as rather important, since it is a conclusion based on many years of actual experience.

Mr. Thomas points out that there are cases where it is un-economical to correct the power factor. The cases he cited may in general, perhaps, be called installations which are not working to their full capacity. The suggested method of gradually adding to the system power-factor correcting devices is, no doubt, very sound, because any system which is underloaded in the beginning will sooner or later be fully loaded, and it is then when the power-factor correction has the most beneficial effect.

Mr. Thomas' recommendation of operating transmission lines with high power factor reminds me of a statement made to me sometime ago by one of the engineers who was instrumental in bringing about our so-called "superpower system." He stated that the greatest difficulty encountered in these systems is caused by the lagging current, which is "kicked around" from one power plant to another like a football. When operator A finds ex-cessive, wattless currents, he changes the excitation of his generator and shifts the current to operator V and vice versa.

Mr. G. S. Smith presents a very interesting oscillographic study of the Fynn-Weichsel motor when operating as a generator. These test results are extremely instructive and valuable. His test results throw a great deal of light on the somewhat puzzling conditions which arise when these machines operate as generators.

For those who are interested in this problem, a circle diagram of a Fynn-Weichsel motor is given in Fig. 7. This diagram has been derived by me a long time ago and has been used extensively in the actual design of machines. It is based on the assumption that the ohmic resistance in the primary member is negligible, a fact which is very nearly satisfied in actual machines. The angle found by the diameter of the circle forms and the vertical must be made equal to the angle between d-c. brush axis and d-c. field axis in the machine. The distance between any point of the circle from the horizontal line $O-1$ represents the input to the machine. When the angle, α, is zero, the brush axis coincides with the field axis. For this condition, all points of the circle lie above the base line, meaning that the machine can operate as a motor only. However, if the brush axis forms a certain angle with the field axis, one part of the circle lies below the horizontal $O-1$ and, q, therefore, represents negative input, meaning the machine operates as a generator.
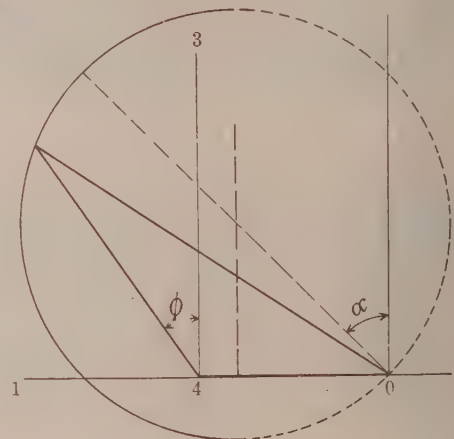
Fig. 7—Circle Diagram of Fynn-Weichsel Motor

If, for instance, the brush displacement is 90 deg. in direction of rotation, the machine is just as powerful as a generator as it is as a motor. If the brush axis is shifted 180 deg., then the entire circle lies below the horizontal $O-1$, meaning the machine can operate as a generator only.

This circle diagram also shows when the machine is capable of delivering magnetizing current to the line and when it draws magnetizing current from the line. As long as the points of the circle lie to the left of the line $3-4$, the machine delivers magneti-zing current into the system, and when the points of the circle lie to the right of the line $3-4$, the machine takes magnetizing cur-rent out of the system. This is true whether the machine oper-ates as a motor or as a generator.

Mr. Underhill recommends improving the power factor in an installation by properly selecting the size of the induction motors in respect to the load which they have to carry. There is no doubt that by this method a very great improvement in the power factor of the system can be obtained. I like to call attention, however, to some of its limitations. Many industries exist in which the load on the machinery is seasonal and in such cases it is not advisable to change the capacity of the motors in accordance with the seasonal business of the industry. There are also many cases where motors must carry, for a relatively short time, heavy loads and, for great periods of time, operate at no load or frac-tional load. Frequently the capacity of a squirrel-cage motor is

governed rather by the starting requirements than by the running load.

These conditions can be particularly well cared for by installing machines which operate at unity or leading power factor for most of the time such as described in the paper. Installations of this kind also overcome the difficulty which Mr. Underhill pointed out that heavy leading currents exist in the wiring in such cases where the power-factor correction is obtained by centralized power-factor correcting devices, such as synchronous condensers or static condensers.

V. A. Fynn (Communicated after adjournment): In Mr. Weichsel's paper there appears to be an indefiniteness in his statements as to the torque conditions in general and particularly as to synchronizing-torque conditions of the machine known under the trade name Fynn-Weichsel motor.

The easiest way to avoid the numerous pitfalls scattered within this field and to gain a *true picture* and a true physical conception of what really happens in the machine is to deal separately with the torque produced by the currents *induced* in the windings F and A of Mr. Weichsel's Fig. 4 and that due to the currents *conduced* or injected into F.

The first is nothing more or less than the well known *polyphase induction-motor torque*. It is known that, under balanced conditions, this induction-motor torque is practically constant at subsynchronous speeds *and becomes zero at synchronism*. It is further known that its value may be varied by varying the impedance of the secondaries to which it is due. We are also advised of the fact that under unbalanced conditions, for instance with different impedances in the circuits of the several secondaries, this induction-motor torque loses its constancy and becomes undulating.

The *nature* of the second torque, that due to the currents *conduced into* the secondary winding F by way of the brushes co-operating with the commuted winding on the primary, and to which I refer as the *synchronizing torque*, is *entirely different*. The synchronizing torque in the motor under discussion is *never constant at subsynchronous speeds* and *does not become zero* at synchronism. At subsynchronous speeds this torque may be an alternating torque of double-slip frequency with equal positive and negative maxima or it may be a unidirectional torque; pulsating from zero to a maximum at slip frequency, all according to the magnitude of the angle α of Fig. 4. As synchronism is approached, the amplitude of the synchronizing torque *increases* and its frequency *decreases*, while the magnitude of the aforesaid induction-motor torque *decreases* and its frequency, which is zero throughout, remains *constant*. At synchronism the frequency of the synchronizing torque is zero, the magnitude of the induction-motor torque is zero and the synchronizing torque becomes the motive torque of the synchronous motor.

At the beginning the statements are indefinite and convey an erroneous idea of the function of the brush voltage in conjunction with the winding F, which incorrect idea is later fostered by the curves of Fig. 10.

A machine connected as in Figs. 5A and 5B starts and operates like an ordinary induction motor, approaches synchronism but never reaches it. Synchronism cannot be reached unless the winding F is connected to the brushes co-operating with the commuted winding which results in the production of an alternating synchronizing torque with equal or unequal positive and negative maxima, said torque being added to or superposed on the ordinary induction-motor torque.

The resistance, or more broadly, the impedance of the secondary circuits affects the induction-motor torque and the synchronizing torque in like manner and is *not* the determining factor in the situation. The difference between the two torques and that which makes it possible for the *conduced* ampere-turns in F to synchronize the motor is the fact that, while the amplitude of the voltage induced in F diminishes to zero with decreasing slip, that of the voltage conduced into F remains constant for all rotor speed. See lines 1 and 2 of Fig. 7.

The fact that the frequency of the brush voltage is inherently the same as that of the voltage induced in the secondaries is not in itself sufficient to cause the additional torque to help the induction-motor torque. The determining factor in this case is *the phase* of said brush voltage with respect to that of the voltage induced in the secondary on which the brush voltage is impressed. The additional torque due to the brush current in F, may, according to the phase of the brush voltage, either help or oppose the induction-motor torque or alternately help and oppose same, but in no case is this torque constant and comparable to the induction-motor torque. At its best this additional "synchronizing" torque pulsates from zero to a positive maximum.

The amplitude of this superposed pulsating or alternating torque is practically independent of speed variations of the order of magnitude of the slip of an induction motor from no-load to maximum load for the reasons that the brush voltage is independent of the rotor speed and that whatever changes in the magnitude and configuration of the synchronizing torque do take place when the motor speed varies are due to changes in phase and magnitude of the brush current in F. These changes are brought about by the change in the frequency of the brush voltage, which frequency increases with increasing slip. *Such being the case, the machine described by Mr. Weischel cannot run at a constant speed as an induction motor.* The fact of the matter is that while the synchronizing torque is indispensable if the motor is to be operated synchronously, said torque *interferes* with the proper operation of the machine as an induction motor, causing the motor speed to pulsate continuously. It is therefore not correct to say simply that the Fynn-Weichsel motor will operate at a higher speed than an induction motor when operating under otherwise equal conditions. Except for the roughest kind of work this machine is unsuitable for use at other than synchronous speeds.

Judging by statements made in the paper, Figs. 8 and 9 have reference to an induction motor operating very near synchronism with a small slip, say, at full load or at less than full load; under no other conditions are secondary voltage and current nearly in phase. We all know that under these conditions the induction-motor torque in balanced circuits is constant and varies with the slip about as shown by Curve 1 of Fig. 10. All we are interested in is how the torque conditions are modified when the commuted winding located on the primary is included in the circuit of the secondary F. Mr. Weichsel's suggestion is that in case the brushes cooperating with the primary commuted winding are coaxial with F, the torque conditions are modified as shown in his Fig. 9c. This figure is qualitatively and quantitively incorrect, the quantitative error is so great as to give a quite erroneous impression of the true nature of the machine.

According to Fig. 8B and column 2 of the fifth page, when the two secondary windings A and F are short-circuited, the resultant torque, $T = T_1 + T_2$, is constant. If so, then T_1, which is due to F, must be less when the brushes and the commuted windings are included in the circuit F, thus increasing its impedance. In Fig. 9c the sum of T_1 and T_2 must therefore be a wave and not a straight line. This is the qualitative error.

The very misleading quantitative error is found in the relative amplitudes assigned in Fig. 9c to the induction-motor torque $(T_1 + T_2)$ and to the synchronizing torque T_3. The ratio of these amplitudes scales 9.6 to 2.6.

At synchronism, or at very small slips $T_1 + T_2 = O$, or practically so, as stated in the paper, is 230 per cent of the full-load torque. The ratio of the amplitudes is then as O to 230 and Fig. 9c is clearly not drawn for nearly synchronous speeds.

At full-load a synchronous torque, the slip, according to Curve 1 of Fig. 10, is about 3 per cent. Since the amplitude of T_2 for a given brush angle α depends on the amplitude of the brush voltage which is constant and on the impedance of F which is zero at synchronism and increases with increasing slip, it is clear

that for a 3 per cent slip T_3 is very little less than its synchronous value and the ratio of induction-motor torque amplitude to synchronizing-torque amplitude is practically as 1 to 2.3. Fig. 9c is evidently far from being correct for an asynchronous torque equal to the full-load torque of the motor.

But even quite near the maximum asynchronous torque, when the slip is 10 per cent according to Curve 1 of Fig. 10, the ratio in question is still as 2.9 to about 1.9. This is an extreme case quite outside the limits specified as those on which Fig. 9c is based, yet this figure no more applies here than it does at loads up to and including full load.

Making the amplitude of T_3 about 8½ times greater than shown or 2.3 times greater than that of $(T_1 + T_2)$ in Fig. 9c puts a *very* different complexion on the proposition and forcibly brings out the fact I have previously stated, *i. e.*, that such a motor *cannot* run at a constant speed when operating as an induction motor.

When the axis of the brushes cooperating with the commuted winding on the primary is displaced from the axis of F by a small angle such as α of Fig. 4, the synchronizing torque T_3 assumes the configuration indicated in Fig. 12, it becomes alternating with unequal maxima and still effectively prevents the machine from running at a constant speed when operating asynchronously. As the magnitude of the negative maxima increases, so does the asynchronous overload capacity decrease.

The Curves 4, 5 and 6 of Fig. 10 have evidently been derived on the assumption that the Curves 1, 2 and 3 represent the induction-motor speed-torque curves of the machine for given impedances of the secondary circuits, that the addition of the brush voltage e_c does not change said impedances and that e_c is constant and cophasal with the voltage induced in the winding into which it is introduced. If all this were true, which is not the case, then it would be permissible to say that the secondary current *in the phase into which e_c is introduced* and consequently *the torque due to that phase* is increased in the ratio of $e_o s_x$ to $(e_o s_x + e_c)$ *but* in his Fig. 10, Mr. Weichsel has not only represented this increased torque as if it were *constant* but as if it were applied to *both* secondary phases.

In Fig. 10, Mr. Weichsel has added *the maximum value of the single-phase, pulsating torque, T_3, produced by the winding, F, only* to the *constant* induction motor $(T_1 + T_2)$ represented by the Curves 1, 2, 3 and *offers their sum as the resultant torque of the motor!*

It is further to be noted that if the conditions were actually such as indicated by Mr. Weichsel's Fig. 10, the machine could not run synchronously unless the torque required was 230 per cent of the normal, see point A of Fig. 10. For smaller torque demands the motor would run at speeds greatly exceeding the synchronous.

Errors of this kind are not so likely to occur if the synchronizing torque is dealt with quite independently of the induction-motor torque.

Pursuing this subject a little further, let us examine into the operation of the motor on the basis of the performance curves shown in Fig. 28. Further on, it is stated that the synchronizing torque T_3 for these motors as designed is from 90 to 95 per cent of the synchronous pull-out torque. For the 75-h. p. of Fig. 28 the synchronous pull-out torque is 196 per cent and the synchronizing torque is therefore at least 0.9×196 or 176 per cent. We can simplify the argument without missing the moral by assuming that T_3 remains constant down to the asynchronous breakdown point. We, of course, know that this torque actually diminishes with increasing slip. Upon the demand of a 197 per cent torque, which is slightly in excess of the maximum synchronous, the machine lapses into asynchronism and the synchronizing torque of 176 per cent reappears but is alternating with very unequal maxima. If $\alpha = 20$ deg. and the positive maximum is 176 per cent, then the negative maximum is 5.6 per cent. The positive maximum is almost sufficient to handle the load and a very small

asynchronous slip corresponding to a 20 per cent asynchronous torque will supply the difference. When T_3 is at its negative maximum the slip must be sufficient to counteract this negative torque and to handle the load, which means that the slip must correspond to a 202.6 per cent asynchronous torque. The motor speed must and does vary accordingly as can be observed on any such motor.

Again, Mr. Weichsel says that the inherent slip of the so-called Fynn-Weichsel motor should be made as small as possible. This means that the winding A of Fig. 4 must have about as much copper as the winding F. Since A is *idle* at synchronism and comes into play only in asynchronous operation, at starting and under loads in excess of the maximum synchronous load, a large amount of copper in A can only be justified if the asynchronous overload capacity is actually utilized. I have shown that this asynchronous overload capacity is only available for the roughest kind of work because the speed then fluctuates continuously and Mr. Weichsel's Fig. 28 clearly indicates that the asynchronous overload capacity is not really relied upon by the makers of this machine. The synchronous overload is about 188 per cent for the 15 and 196 per cent for the 75-h. p. motors to which said figure refers. This overload is ample for all ordinary purposes and the asynchronous overload which rises to 300 per cent and 308 per cent respectively is pure waste, it cannot be and is not utilized.

Mr. Weichsel's third conclusion states that the injected current must be about twice as large as the full-load secondary current of the motor. This means that the commutator must carry at least twice the normal full-load secondary current near the synchronous break-down point and if the asynchronous overload capacity is really utilized, as suggested in the paper, then *the commutator must carry more than three times the normal full-load secondary current* when the machine operates near its asynchronous break-down point. I do not think it can be fairly said that such a commutator has relatively small dimensions, yet such is Mr. Weichsel's contention.

Much is made in the paper of a really insignificant detail and a quite erroneous impression is conveyed: Fig. 21 purports to show that the axis of the unidirectional magnetization on the secondary does not coincide with the axis of the winding F because of the d-c. ampere-turns in the primary commuted winding and it *also* purports to show that these primary d-c. ampere-turns are neutralized by the a-c. ampere-turns on the primary.

In the paper, it is also stated that the armature, *i. e.*, the primary, d-c. ampere-turns are about 5 per cent of the primary a-c. ampere-turns. It is stated that α shall be zero, or very small. From Fig. 18, and in fact without it, we know that the secondary ampere-turns in synchronous operation must be greatly in excess of the primary ampere-turns. In Fig. 21 the vector $A T_{adc}$ must then be much less than 5 per cent of the vector $A T_f$ and the angle between the two should be smaller rather than greater than that shown. How can these insignificant primary d-c. ampere-turns influence the location of the "resultant direct-current field" to any appreciable extent? In Fig. 21 the "d-c. armature field" is shown as amounting to 54 per cent of $A T_f$, hence the delusion.

As to the suggestion that these primary d-c. ampere-turns are neutralized by some of the primary a-c. ampere-turns,—of course they are, *but* he must either say that the "d-c. armature field" is neutralized by some of the a-c. ampere-turns and continue to figure with $A T_f$ only or he must figure with the "resultant direct-current field" and forget about this neutralization.

In dealing with commutation, Mr. Weichsel says that the reactance voltage is similar to the reactance voltage in a standard d-c. machine. It would be quite correct to say that it is identical, *i. e.*, identical in nature, but it is not even similar as to magnitude. The sides of the coil undergoing commutation in the standard d-c. machine lie in the open, *i. e.*, in the interpolar space; in this machine these coils are surrounded

by laminations separated by an induction-motor air gap and, for otherwise equal conditions, the reactance voltage in this case is a multiple of that of a standard d-c. machine. The brush voltage and the current per conductor must be kept low.

When $\alpha = O$ the coils undergoing commutation cut the full resultant magnetization, i. e., the full field flux of this motor at

FIG. 8

FIG. 9

FIGS. 8-9—POWER-FACTOR-LOAD CHARACTERISTICS OF
SYNCHRONOUS INDUCTION MOTOR

no load, and cut no field flux at maximum synchronous load. For other values of α the no-load conditions improve, the maximum load conditions get worse. Mr. Weichsel's arguments as to the advantages of a concentric over a diamond winding are beside the point for either can be used in an ordinary induction motor. As to his arguments in appendix No. 2, it is true that by taking $2/3$ of the three-phase secondary and feeding into it a d-c. equal to $\hat{i}\sqrt{3/2}$ the flux and the loss will be the same

as with an effective three-phase current $\hat{i}$ in each of the three rotor phases, but this loss will be distributed over two instead of three phases and the heating will be considerably greater.

Furthermore, the secondary ampere-turns in synchronous operation, with unity or leading power factor, are considerably greater than the secondary ampere-turns for corresponding asynchronous operation as is shown in Mr. Weichsel's Fig. 24 where the secondary ampere-turns for a certain load are $1-2$ or A for synchronous, and $1-3$ or B for the non-synchronous operation. The ratio of A to B is as 30 to 19, and the d-c. in the two phases of Mr. Weichsel's Fig. 35 must therefore be $\hat{i} \times \sqrt{3/2} \times 30/19$ or 1.58 times greater than indicated by him.

If the amount of copper on the secondary of the synchronous induction motor is no greater than that used when the machine is designed as a straight induction motor and if two-thirds of that copper is used for the unidirectional ampere-turns in synchronous operation, then for the load conditions of Fig. 24 the secondary copper losses will be 2.49 times as great as the corresponding slip losses in non-synchronous operation and the cooling surface for this loss will have been reduced to two-thirds of that available in the straight induction motor.

The question may well be asked, why not also use the third phase of Fig. 35? One reason is that it is necessary to have a polyphase winding on the secondary not only for starting but also to prevent hunting in synchronous operation and to take care of

FIG. 10—CIRCLE DIAGRAM OF SYNCHRONOUS INDUCTION MOTOR

loads in excess of the maximum synchronous load and give the motor a chance to work back into synchronism when a sudden overload causes it to lapse into asynchronism. Mr. Weichsel even thinks, (see his conclusion No. 2 on the eighth page,) that this polyphase winding should be such as to reduce the induction motor slip to very small values. The third phase of Fig. 35 is really the winding A of Fig. 4.

Another reason for not using all three secondary phases to carry the unidirectional ampere-turns is the fact that when so used they form a winding distributed over all the pole surface and with but one axis per pole pair. To get the same flux with three phases in circuit instead of only two would require a further increase of 33 per cent in the ampere-turns and a consequent 77 per cent increase in copper losses. But utilizing the third phase increases the amount of copper by 50 per cent so that by using all three secondary phases, i. e., all of the available secondary copper, for carrying the secondary unidirectional ampere-turns the secondary copper losses become equal to $2.49 \times 1.77 \times 2/3 = 2.94$. This means that for the load conditions of Fig. 24 and on the assumption of an unchanged amount of copper on the secondary, all of said copper being used to carry the d-c. ampere-turns, the secondary copper losses in synchronous operation are practically three times as great as those in non-synchronous running while the cooling surface is the same.

The watts loss per unity of cooling surface is some 22 per cent less when all three instead of only two of the secondary phases are used for carrying the secondary unidirectional ampere-turns but

the total secondary copper loss is 18 per cent greater and no copper is available for the additional secondary winding A of Mr. Weichsel's Fig. 4.

The fact is that a synchronous induction motor of the form under reference *can* be built in which the secondary copper losses are not materially greater than the corresponding losses in an equivalent induction motor *but* such a machine must have *much more active material than the equivalent induction motor and must be correspondingly more costly.*

The ordinary synchronous condenser is difficult to start and is very sensitive to line voltage or to frequency disturbances. It is very liable to fall out of step and cause oscillations throughout the system. The machine under reference is very easy to start and if it does fall out of step it will automatically go back to synchronism without fuss or trouble so soon as the disturbance is over.

The fact that the primary is on the revolving member and the primary currents are taken to it over slip rings is a serious objection to the machine as a motor, but much less so as a synchronous condenser. Slip-rings which carry current all the time are almost as touchy as a commutator. As a synchronous condenser the machine can be located without reference to any other machinery and therefore in some dry, clean and sheltered spot favorable to slip-ring operation.

The fact that the commutator carries load as well as exciting currents and the fact that any accident to the brush circuit must put the machine out of commission, since the winding A alone is insufficient to permit the machine to operate as an induction motor, also militate against its general use as a motor for no one cares to run the risk of an interruption in production. These same facts lose much of their significance when the machine is used as a synchronous converter. The sheltered position to which it can then aspire makes commutator operation easier and a break-down less likely. If one does occur, it does not entail an interruption in production but merely the temporary loss of the advantages conferred by a synchronous condenser.

Another important point, relates to the power-factor-load-characteristic of such machines. The fact is that the possible inherent compounding or power-factor-load-characteristics of this machine do not permit of operation at unity power factor at all loads as clearly appears from my Figs. 7 and 8 herewith. Generally speaking, the power factor leads considerably at light loads, tends towards unity with increasing load, reaches unity near maximum synchronous torque and lags thereafter. This characteristic is suitable for a synchronous condenser but not for a general-purpose motor. It cannot be sufficiently emphasized that in so far as losses are concerned, whether in the motor, in the transformers, in the line or in the generators, a leading current is just as objectionable as a lagging one. The one exception is in connection with the exciting current of the generators.

For the benefit of those who desire to study the compounding characteristic possibilities of these machines more closely, I append the circle diagram Fig. 10. The terminal voltage is E_t and the resultant motor magnetization is R, corresponding to $A T_m$ of Mr. Weichsel's Fig. 18. The brush angle is α, the location of the winding F is indicated by the coil on vector $O-15$. The locus for the unidirectional secondary magnetization F is the circle 17, the primary current is I, the phase angle is φ, while c and δ are the angular displacements between R and F and between R and the brush axis respectively. The vectors E_t and R are supposed to be stationary in space and the brushes and the winding F are moved counterclockwise through 180 deg. while retaining their proper angular relation α. This covers all possible load conditions for either polarity. The curves in Fig. 9 were calculated from the diagram of Fig. 10. The angle α is 22.5 deg. in both figures.

In my opinion, the motor described by Mr. Weichsel *is not a general-purpose motor.*

H. Weichsel (by letter): After carefully reading Mr. Fynn's later discussion of my paper, I conclude that while he and I approach the theoretical analysis of this type of motor somewhat differently, the reader will not be interested in a prolonged discussion of such differences from our respective points of view, particularly when actual commercial results secured with the Fynn-Weichsel motor bear out the analysis presented in my paper. I will confine my closing remarks in the discussion to a reference to some of the points in Mr. Fynn's discussion where his conclusions are erroneous and where the actual service performance of the motors conclusively supports my point of view. I shall make no reference to those paragraphs which I deem of minor importance.

While participating in the early theoretical development of the Fynn-Weichsel motor, Mr. Fynn has not had the advantage of contact with the commercial development and has probably not had access to actual performance test data of the character to which I refer below.

Before replying to some of the different criticisms which Mr. Fynn has made in his communication, I desire to state that those parts of my paper which deal with the working principle of this machine have, as their main object, the presentation of *fundamental* laws which govern the working of this new type of machine. It was my purpose to free these explanations, as much as possible, from any secondary considerations that would tend to obscure the main fundamental laws.

I regret, therefore, that Mr. Fynn has found it advisable to criticise several of my statements and conclusions on the ground that they lack accuracy, and also that he has entered into a discussion of various details.

In presenting the theory of the starting and synchronizing performance, my reason for the line of discussion pursued in my paper grew out of my desire to give the reader the train of thought which had led me to the discovery that a motor of this type must develop a very powerful torque when the d-c. brushes coincide with the axis of the d-c. field winding, and develop a diminishing synchronizing torque as the brushes are moved out of this position.

The first public statement giving the reasons for the remarkable synchronizing torque of this new type of motor were made by me, February 16, 1925, before the Association of Iron and Steel Electrical Engineers in Pittsburgh.

In the early part of his written communication, Mr. Fynn repeats, in different wording, the statement made in my paper in connection with Figs. 6 and 12 and also the conclusions referred to by me in regard thereto; as well as further statements made in connection with Figs. 9, 11, 12, and 13 of my paper; also, my Fig. 10 and corresponding text.

By some of these statements, Mr. Fynn conveys the impression that I set forth variations in resistance as the "determining factor" with respect to synchronizing torque. It will, however, be found that I also fully discuss the bearing of the phase of the brush voltage upon this matter.

Considerable emphasis is laid by Mr. Fynn upon the fluctuations of torque after the motor has been overloaded to a point pulling it out of synchronism and resulting in its operation as an induction motor. As stated in my paper, it is true that there are very rapid pulsations in torque under these conditions, but it must be remembered that there are not corresponding variations of speed of the motor.

The corresponding speed variations of the motor are considerably less than the torque variations, because of the inertia of the rotor and of the driven load. These relations are similar to those which hold the speed fluctuations of a reciprocating engine low. Fig. 11 herewith illustrates an oscillogram taken by the University of Washington, showing the line-current fluctuations under such conditions. These fluctuations are of somewhat of the same order of magnitude as the torque fluctuations.

In practise, neither the current nor speed variations are found detrimental to the electric service, nor to the durability of the motor when such temporary overload conditions are not excessively prolonged. A very interesting demonstration of this fact is a commercial installation of the Fynn-Weichsel motor driving a high-speed grinding wheel. On every service use of the grinding wheel the Fynn-Weichsel motor is pulled out of synchronism, immediately returning to synchronism on the withdrawal of the excessive load from the face of the emery wheel. This installation has been in operation for over a year and while not a recommended type of service for the Fynn-Weichsel motor, it has proved a very interesting application, having been made solely for the purpose of testing the physical result of such service upon this type of motor, and having demonstrated two important factors—

First, that the service does not disturb adjacent motors operating from the same circuit;

Second, that there has been no deterioration of the Fynn-Weichsel motor under these conditions of service.

A further fact might be noted—that the operator of the grinding wheel is unconscious of the motor changing from the synchronous to the induction operating characteristic. Actual tests made with a tachometer on a 100-h. p., 600-rev. per min. motor, as well as on several smaller sizes, showed no measurable speed fluctuations when the machine operated as an induction

FIG. 11—SYNCHRONOUS TO INDUCTION OPERATION OF FYNN-WEICHSEL MOTOR

V_1 is the timing wave. V_2 is the line voltage. V_3 Line current.

motor; i. e., beyond its horse power capacity as a synchronous machine.

Mr. Fynn attacks my Fig. 9c on the ground that this figure represents conditions when the motor operates very nearly at synchronism, and he states that, under such conditions, the ratio of torque $T-3$ to $T-1$ plus $T-2$ is materially larger than shown in my Fig. 9c.

The error in Mr. Fynn's statement will be found in his sentence "with a small slip at full load or at less than full load and under *no other conditions* are the secondary voltages and currents nearly in phase."

In that part of my paper which precedes my discussion of Fig. 5, it is clearly stated that the secondary voltage and currents in a machine containing leakage are nearly in phase when the currents do not materially exceed the full-load value.

Such a condition exists not only when the machine operates with small slip and no external resistance in the secondary but *also* when the machine operates with large slip and large resistance in the secondary, such as, for instance, occurs during the starting period of the machine. This is in exact agreement with the phenomena which occur in this respect in connection with standard slip ring induction motors.

My Fig. 9c pictures correctly the conditions represented

in my Fig. 10 by Curves 2 and 5 for a speed of about 80 per cent of synchronous speed and a load approximately equal to full load torque. Mr. Fynn's arguments and conclusions in this connection are, therefore, wrong, due to the faulty assumption upon which they have been based.

He states that serious mistakes exist in my Fig. 10 and asserts that I had represented the increased torque due to the injected voltage e_c not only as if it were constant but as if it were applied to both secondary phases. Further, he states that I added the maximum value of the single-phase, pulsating torque, $T-3$, produced by winding F, to the constant induction motor torque, $T-1$, plus $T-2$, and offered their sum as the resultant torque of the motor. This is a misunderstanding of the statements made in my paper. In connection with Fig. 9, I fully explained that the torque due to the injected voltage, e_c, is pulsating. In the first part of my paper there is a statement as follows: "Therefore, if the load connected to the primary has a fairly large amount of inertia the *average* torque available on the motor lies about half way between the induction motor speed torque curve and the speed torque curve which is shown in Fig. 10." This statement definitely contradicts Mr. Fynn's assertion that I had assumed the torque due to the injected voltage as constant.

Referring to his second claim, that I presented the increased torque due to injected e. m. f. as if it were applied to both secondary phases, I state: "The conditions in the winding A cannot in any manner be altered by injecting a current in winding F, and, therefore, the torque produced by winding A remains unaltered, etc."

The mistake made by Mr. Fynn lies in *his assumption* that the horizontal difference between Curves 1 and 6. or 2 and 5. or 3 and 4, represents an *average* torque. However, no such statement has been made by me, but one to the contrary in that part of the paper just cited, where I pointed out that this torque difference fluctuates. The length of the horizontal line between Curves 5 and 6 represents the time maximum of the torque due to the injected voltage. That this relation must exist not only follows from the text of my paper but also directly from Fig. 10, where the length of the line, $100-A$, represents the *maximum* torque of the motor when operating at synchronism; and the maximum torque of a motor at synchronism must, by the nature of things, be also the maximum torque immediately before synchronism is reached.

The wrong assumptions made by Mr. Fynn also led him to the misstatement in regard to the resultant torque of the motor.

The most erroneous statement is where he says that if conditions are actually as indicated in my Fig. 10 "the machine could not run synchronously unless the torque required was 230 per cent of normal. For smaller torque demands the motor would run at speeds greatly exceeding this synchronous speed." This statement is in contradiction to my Fig. 10, where the speed-torque curve of the motor, with no external resistance in the secondary, is given by the curve, $100-A-6$. The part $100-A$ of this curve corresponds to loads from zero to 230 per cent and during this part, the speed torque curve is a horizontal line passing through the 100 point, which means that the speed is independent of the load.

Statement is made that an asynchronous overload of 300 per cent is pure waste. This is completely overlooking the fact that an important factor in this type of machine is its synchronizing ability. A machine whose maximum torque as a synchronous motor is 200 per cent can synchronize a load of 200 per cent, provided the load is a pure friction load. If, however, the inertia is very excessive, the same machine can synchronize only about 100 per cent full load, as explained in my paper. However, this latter extreme condition is never accounted for in practise. Therefore, in order to provide an ample margin for safely synchronizing full-load torque, or more, under almost any kind of load which may be met in practise, it is *essential* to give these motors a maximum syn-

chronous horse-power capacity in the neighborhood of 200 per cent. The overload capacity of the machine as an asynchronous motor is incidental and is achieved without extra expense.

Later in his written discussion, Mr. Fynn appears to create the impression that the commutator must be dimensioned for three times normal load secondary current. Anyone familiar with the design of motors knows that it is useless to dimension electrical
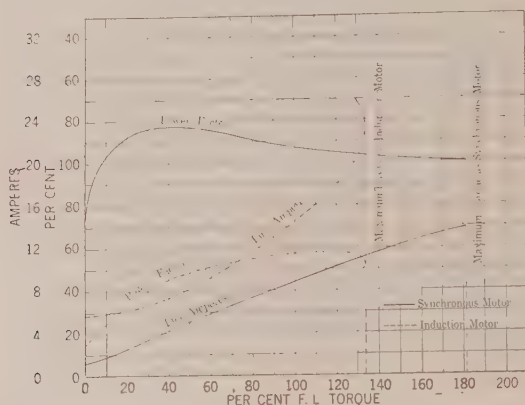

FIG. 12—7½-H. P., 60-CYCLE, FOUR-POLE, THREE-PHASE FYNN-WEICHSEL MOTOR OPERATING AS SYNCHRONOUS MOTOR AND INDUCTION MOTOR

parts of a machine in accordance with the momentary overload which the machine can carry. A glance at Fig. 3 of my paper justifies my statement there that the commutator is relatively small.

Again my Fig. 21 is criticized because it is not drawn to scale. It is a generally accepted expedient to do this in such cases in which some of the vectors would otherwise nearly coincide. The main object, as indicated by the italicized letters in the text
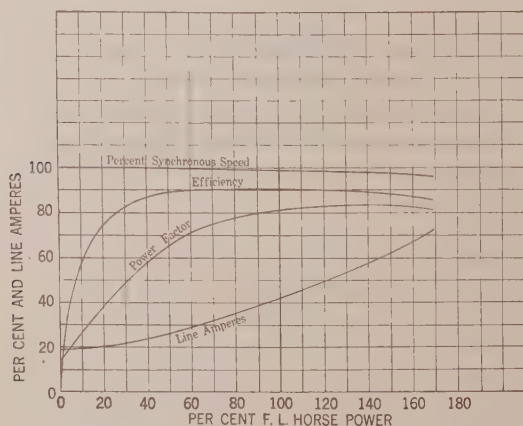

FIG. 13—PERFORMANCE CURVES FOR FYNN-WEICHSEL MOTOR

15-h. p., Four-pole, Three-phase, 60-cycles, 220-volts. Operated at normal voltage as an Induction Motor.

belonging to this figure, is to show that, at any load, the d-c. armature ampere-turns are counterbalanced by equivalent a-c. ampere-turns. Mr. Fynn now thinks that this is selfevident. My diagram Fig. 21 proves that the Fynn-Weichsel motor does *not* operate as a synchronous converter, because only a *small* part of the a-c. ampere-turns is used to counterbalance the d-c. ampere-turns, while in a converter, the a-c. and d-c. ampere-turns are essentially of the same magnitude and opposed.

Further on, he criticizes my statement that this new motor operates from commutating point of view similar to a neutralized d-c. machine in which the neutralizing winding is weaker than the d-c. armature reaction. In my judgment, this statement pictures the analogy quite correctly in view of the fact that the d-c. armature field is, at any time, completely neutralized as shown in my Fig. 21, but the component of the resultant field, which is in line with the brush axis, is not wiped out. If the brushes are shifted in the direction of rotation, which is the only practical way of shifting them, the commutation conditions for the maximum load point frequently first improve, and, by a still fur-
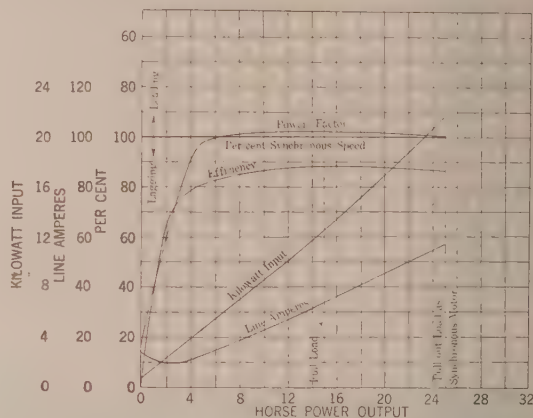
FIG. 14
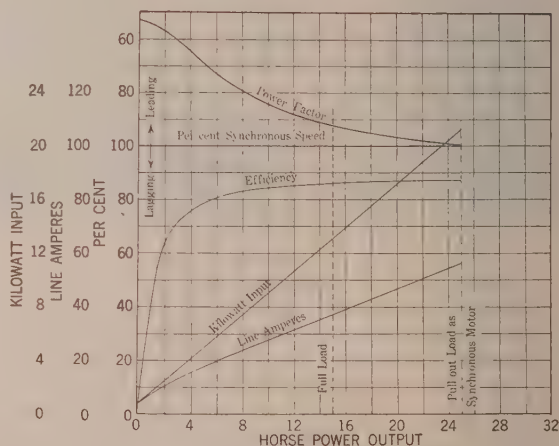
FIG. 15

FIGS. 14-15—CHARACTERISTIC CURVE OF FYNN-WEICHSEL MOTOR

This is a 15-h. p., four-pole, 60-cycle, three-phase motor. In Fig. 14 it is shown adjusted for approximately unity power factor. In Fig. 15, it is adjusted for leading power factor.

ther shift, become more difficult. By suitably selecting the magnitude of different constants of the machine, such as brush-angle, leakage-reactance, etc., it is possible to obtain the point of theoretically correct commutation for almost any load point desired.

Still further on Mr. Fynn arrives at certain conclusions regarding the heating and losses of these machines. His reasoning that, for equal losses, a winding covering only two-thirds of the circumference must be very much hotter than a winding having

the same losses but with them distributed over the whole circumference, is a quite common argument, but actual experience has proved this to be wrong. If his views were correct, it would be necessary to use larger sizes of copper for certain coils in the armature of a standard synchronous converter, and this practical experience has proven to be unjustifiable.

In the "induction type of synchronous motors," such as is built in Europe, one part of the winding has four times the loss of the remaining winding, when equal copper section is used for all coils. Experience has shown that equal copper section for all coils can be used without resulting in unallowable inequality of heating. The Metropolitan-Vickers Company, in their circular No. 1041, December, 1921, describing this type of motor, state on page 7: "For manufacturing reasons the cross-section of the conductors is kept the same in all three phases, so that the heating is slightly unequal in the different parts of the winding. But due to the relatively large heat capacity of the iron, the temperature rise is practically uniform around the rotor."

With reference to Mr. Fynn's theoretical objection to the Fynn-Weichsel motor, that the primary currents are supplied through slip-rings, I shall merely say that extended and satisfactory experience with a large number of installations using these machines as general-purpose motors should be considered sufficient answer.

Mr. Fynn also suggests that any trouble with the commutator or brush mechanism will "put the machine out of commission." He quite overlooks, or neglects to state, that if the exciting current were suddenly broken, the Fynn-Weichsel motor would continue to operate as a polyphase induction motor with a single-phase secondary and load characteristics as shown in Fig. 12 herewith.

Normal load capacity of the motor under such circumstances can be fully restored by short-circuiting the excitation field winding, in which event, the motor will operate as a normal slip-ring, induction-type motor, as illustrated in Fig. 13. Figs. 12 and 13 are characteristic curves of all sizes of Fynn-Weichsel motors when operated under the conditions indicated.

Mr. Fynn expresses the view that the Fynn-Weichsel motor is not a general-purpose motor. It is being marketed as such and as such, is meeting with a most favorable reception. It can be installed whenever a good general-purpose d-c. motor can be installed, and the manufacturers are finding a surprising number of installations where the synchronous-speed characteristic is proving more advantageous for production purposes than the primary service of power factor correction. A large number of commercial installations in sizes of motors ranging from 5 h. p. to 150 h. p., all made as general-purpose motor installations, suggests conclusively that the Fynn-Weichsel motor is, in fact, a general-purpose motor.

Mr. Fynn infers that the Fynn-Weichsel motor cannot operate at unity power factor. Fig. 14 illustrates a commercial test made by the Commonwealth Edison Company at Chicago, and it will be observed that the power factor is practically unity throughout the normal load range of the motor, this being a motor not designed for exact unity power factor operation but rather for operation as illustrated in Fig. 15.

Fig. 15 represents the same motor, also tested by the Commonwealth Edison Company, with no other modification than a slight change in the position of the exciting brushes, for the purpose of giving a strong leading power factor and thus compensating for the lagging power factor of an ordinary induction motor of the same size operating in the same plant, giving unity power factor on the two motors in combination.

Numerous corresponding tests have been made by a large number of the leading electric light companies of the country, and what the motor will do with respect to unity or leading power factor is not a matter of theory but of demonstrated fact, and while the above curves are test results on the 15-h. p. motor, similar characteristic performance results are given by motors of all sizes.

Mr. Fynn's employment of a diagram to establish statement that the Fynn-Weichsel motor cannot be designed to operate at approximately unity power factor over a large load range is erroneously employed, assuming design constants which would not be used were the Fynn-Weichsel motor to be designed for unity power factor service.

Mr. Fynn's argument suggests that it would be advantageous and preferable to have these motors operate at unity power factor; in his argument he has overlooked the actual conditions which exist in present installations and probably will for many years to come. Due to the use of a relatively large percentage of induction motors in all installations, it is desirable to have the remaining machines in the installation operate with leading power factor in order to provide the necessary magnetization for the induction motors of this installation.

Discussion at Spring Convention

A NEW TYPE OF HORNLESS LOUD SPEAKER[1]

(Rice and Kellogg)

St. Louis, Mo., April 15, 1925

H. A. Frederick: In reading this paper one cannot but wish that some definite standard or method of rating might have been employed, so that the results of this investigation of many types of loud speakers might be placed quantitatively in definite positions on some scale of merit. Since the authors, as pointed out in the paper, have not as yet been able to obtain satisfactory quantitative measurements with their best designs, the readers are not in a position to judge the accomplishment. While these measurements are not simple and are liable to be misleading, unless very carefully made, still the same comment applies to qualitative judgments by the ear alone.

In this work, the authors have primarily stressed the obtaining of a loud speaker giving high quality; that is, one which faithfully and without distortion reproduces the sound whose electrical counterpart has been fed to it. In striving for this result, it is difficult also to obtain efficiency. In the authors' analysis of the problem they have largely sacrificed considerations of efficiency. For example, the "inertia control" used in their design involves a diaphragm 90 deg. out of phase with its driving force or, in other words, low power factor. They have also neglected motional reactions of the mechanical system on the electrical as well as transition losses due to the connection of vibratory systems of different impedances. The analysis as a result is limited in its field of application. It is probable, on the other hand, that improvements to overcome such losses will be effected and that they will make possible loud speakers of high quality which will also be of materially higher efficiency than those now available.

Another phase of the loud-speaker problem which would seem to warrant consideration is the load capacity. This, of course, must be defined in terms of sound-power output. A loud speaker, to be satisfactory for certain very important classes of service, must be capable of giving out a very considerable amount of sound without having the relation between output and input depart from a linear characteristic. In rating the various types studied it would be of interest to know how they were found to compare on this score; also, it would be of interest to know what were the limits of output found for these most promising designs and whether magnetic or vibratory, namely,

1. See p. 982 of this issue of Journal.

mechanical limitations were first encountered or whether heating of the coil limited its output.

In the favored design, the size of the baffle, of course, sets a lower frequency limit while the size of the cone and its rigidity set a higher frequency limit. It would be of interest to know where these two limiting frequencies were to be found.

Near the end of the paper, it is stated that the stiffness of a magnetic-type motor system can be decreased by weakening the polarizing magnetic system. As pointed out by Hanna[1], the polarizing field gives rise to what might be termed a negative stiffness since it acts in opposition to the mechanical stiffness of the system and, therefore, has the opposite effect to that stated.

The authors state that "if a strong magnetic field is provided, the coil drive gives greater sensitivity than the iron-armature drive." I would like to ask if they would explain a little more in detail just what is meant by sensitivity, and how this conclusion was reached. It would seem that the magnitude of the mechanical force and the mass, as well as the electrical impedance and current, would have to enter a satisfactory expression for sensitivity.

In the article appears the statement that "four times the power is radiated with the baffle as with the back enclosed." Is the conclusion based on theoretical grounds or was it determined entirely by observation?

The reference to the resistance-controlled type as being of only "theoretical interest" might perhaps appear to underestimate its importance since any loud speaker to have high efficiency must be largely resistance-controlled, the resistance coming from useful radiation of sound into the air.

B. F. McNamee: The loud speakers which have been on the market using a movable coil system are supplied (as I suppose this one is) with a field current, usually from a storage battery. I believe that such loud speakers have met with a certain amount of sales resistance, due to that fact. Especially where dry-cell tubes are popular, a source of field current is not very readily available. I would like to ask how permanent field magnets would work out in this case, or what other provision has been made.

V. E. Thelin: In endeavoring to get quality of tone, I have adapted a Western Electric unit to a talking machine which has a wooden tone arm, as well as a wooden horn, and I attribute the fact that the so-called horn effect had disappeared to a considerable extent, to this wooden construction. I compared this combination with a new speaker of the parchment-cone type, and an adaptor type unit of another manufacture. I noticed that the Western Electric unit and the parchment type speaker gave the same volume and tone quality and it was difficult to tell them apart when they were operating at the same time. The adaptor type, however, changed the quality considerably and on the low notes of the piano it was very mushy.

It seems to me that there is a large field for the amplifier unit demonstrated here today. With a unit of this kind, it, no doubt, would be possible to take a phonograph record, and using a needle which has practically no scratching, and, therefore, has perfect tone, but whose music is too soft to be heard in the horn of the talking machine, and amplify it to a considerable volume but still retain the perfect tone quality. In this way it would be possible to preserve the music of the present-day artists on the radio and hear this music many years to come.

I would like to ask Mr. Kellogg if the baffle need be of a certain kind of material for obtaining the best results.

R. S. Glasgow: The authors mention the Hewlett type of loud speaker in their paper and point out that one of its disadvantages is the long air-gap that the radial magnetic field has to traverse, with the result that considerable energy is required for excitation purposes.

I would like to know whether the quality of reproduction would be effected by the substitution of a thin iron diaphragm in place of the non-magnetic materials that are usually employed.

A. Nyman (by letter): The conclusion the authors have drawn from physical considerations is that the resistance control is the ideal for loud speakers; meaning, of course, by the resistance control any control which is proportional to the velocity of the movement of the sound-generating surface. From the ordinary physical consideration the loud speaker can be regarded as an ordinary electric motor with certain peculiar load conditions capable of giving resonance at certain frequencies, elastic control below that frequency, and inertia control above that frequency. It is quite evident that a motor of this type would operate most satisfactorily if the elastic control and the inertia control could be so small as to be negligible compared to the actual load output. Considering the loud speaker from this point of view, it is also evident that if a loud speaker can be designed with a large efficiency that the resistance control will naturally follow.

The problem therefore comes down to the design of a sound-producing structure of such a nature that the energy input from the electrical instrument is converted largely into sound energy and only a very small percentage into elastic or inertia energy. It is also evident that a large horn properly designed in such a way as not to have any permanent resonant characteristics would form an ideal load on the loud speaker, but involves an unwieldy mechanical structure. It has to be quite long before it is suitable. The attempts carried out by the experimenters, using large conical diaphragms apparently discloses the fact that it is difficult to construct a large conical diaphragm that will avoid irregular movements and local resonance difficulties.

In future, the development will be probably in this direction; that is, the construction of a mechanical structure for radiating sound in the space.

Even under the best conditions the energy that can be radiated into the air with an average loudness of sound is quite small. From this it follows that the restoring force, due to the elastic control should be small, and the inertia force should be also small. This condition naturally leads to a low-frequency structure, but consisting of light enough parts to be capable of responding to high-frequency currents. The writers of this paper achieved this object by the construction of a moving-coil unit with a practically floating diaphragm, and a consequent natural frequency of around 100 cycles. It is, however, possible to achieve frequencies as low as this with the ordinary electro-magnetic types of loud speakers, both the steel-diaphragm type and the moving-armature type.

In either of these types there are two forces opposing each other under normal operative conditions. These forces are the elastic forces in the diaphragm, and the magnetic pull of the magnets. Now, it is possible to adjust the relation between these two forces in such a way that the difference between them is quite small. The resulting natural frequency of the whole system is consequently also very small. This can be done without any sacrifice on the part of the strength of magnetization. As a matter of fact, it is necessary to choose a rather soft diaphragm on the moving-iron type in order to achieve this magnetic balance.

The sound-pressure measurements to which the writers refer at the end of the paper are undoubtedly still in a rather imperfect stage and can only afford comparative information on different types of loud speakers. It should be borne in mind, however, that under the best conditions the sound-pressure measurement will not give the complete information on a loud speaker. It is possible to choose a fairly resonant loud-speaker unit and a fairly resonant sound-diaphragm system, which in combination would give sound pressure measurements of almost constant value at different frequencies. However, this loud speaker will not necessarily give good musical or speech reproduction. There is a phenomenon which may be described as persistance of sound in all musical instruments; it has the same effect as the reverberation in large auditoriums, and is caused by

the fact that resonance condition exists. This persistence causes the sound to continue radiating from the sound-distributing structure after the loud speaker has ceased to produce this sound. Of course, if the following note is of a different frequency from the persisting note, and possibly of a frequency causing a musical dissonance, the resulting sound would have a jarring effect in a musical composition. This phenomenon, which is not very well known, and as far as I know, has not been investigated by physical measurements, is however quite pronounced, and if precautions are taken to eliminate it, a considerable improvement in sound quality is possible.

J. P. Minton (communicated after adjournment): In a series of popular articles appearing during the past year in the *Wireless Age* I have pretty well covered the whole field of the ear, the voice and the loud speaker up to the present moment. As a result of this study and experimentation it is clear to me
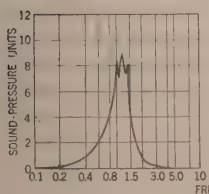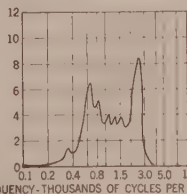

Fig. 1—For the   Fig. 2—For the   Fig. 3—For the
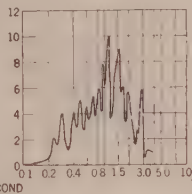   Year 1921   Year 1922   Year 1923

that up to the time, the loud speaker, in spite of improvements, has failed to give entirely satisfactory reproduction. Until the appearance of this new loud speaker, this device has been the weakest link in radio. In this respect radio has suffered in the past the same limitation that the phonograph has existed under. In phonograph reproduction the sound box and its associated horn were the weakest links. Recording was developed to an extent which made it possible to get into the record much more than the sound box and horn were able to give out. In a sense, radio reception has existed under the same impediment. However, radio originally was developed entirely for the transmission of intelligence and not for that of pleasure and entertainment. The requirements and sustaining forces in the two cases, therefore, were quite different. Accordingly, radio was developed to a high degree of perfection while the phonograph has not been so highly developed.

When radio broadcasting and reception came into existence, the already highly developed state of radio made possible the rapid growth of this new form of entertainment and education. The loud speaker had to be injected into this picture. Its use had previously been limited to certain fields of not very great importance. It had not received very serious consideration up to this point. Phonograph quality was quickly attained by use of horns of various sizes and shapes to which were attached units of the usual types. This stage was a temporary one, but it has existed for four or five years. In the meantime, a great deal of fundamental research was undertaken and now as a result of this work the loud speaker has been brought to a point where its performance is such as to make possible the reproduction of the original with an exactness astonishing to all of us.

As the authors have indicated the development has gone through a number of stages and in addition to their own excellent contribution to this work much credit for the gradual evolution of the loud speaker is due to many other workers in this and the allied fields of voice, ear and music analysis. Among the names of those who have contributed most from the fundamental point of view to this work will be found Rapleigh, Lamb, Webster, Stewart, Miller, Foley, from our universities and from our industrial research laboratories will be found such men, in

addition to the present authors, as Hewlett, Slepian, Hanna, Fletcher, Wegel, Crandall, Maxfield, Goldsmith, Ringle, Wolff, Kranz and others.

From the scientific point of view it will be interesting to show a group of six curves which may represent the evolution of the loud speaker. The ordinates in these curves are proportional to sound pressures and the abscissas are frequencies divided by 1000. During the early stages (say 1921) of broadcasting, Curve 1 may represent an average loud speaker. Curve 2 may represent the state of the art in 1922. Curve 3 represents what was obtainable for 1923, Curves 4 and 5 for 1924 and Curve 6 for 1925. These curves represent a steady progress in four or five directions. First, extension of the range of response to include both higher and lower frequencies. Second, uniformity of response, or the gradual elimination of the sharp peaks and depressions. Third, more nearly equal response at all frequencies. Fourth, reduction of non-linear distortion. Fifth, introduction of pure low-frequency response.

Curve 6 represents the performance of the new Rice-Kellogg loud speaker. The curve was taken close up to the loud speaker so that the characteristics of the vibrating system itself, actuated by a constant force, would be obtained. The loud speaker covers quite affectively a frequency range extending from 100 to 7500 and perhaps 10,000 cycles. The response is quite uniform compared with all other types of loud speakers and this new speaker gives an exceedingly small amount of non-linear response and therefore small distortion compared with all other loud speakers.

I wish to call attention to the fact that Curve 6 does not indicate complete agreement between the theory based on inertia action and the response at various frequencies. If the cone followed this simple theory then the response as measured by sound pressure should be constant at the various frequencies. Now, in this particular sample tested the response rises abruptly at 100 cycles; it also falls off abruptly above 6000 or 7000 cycles; there is also quite a marked depression in the region of 2000 cycles and a minor one at 4000 cycles. I am quite inclined to the view, therefore, that, in addition to the inertia-controlled motion which the authors seem to favor, there are also present to a marked extent flexural vibrations which, due to circular and diametral nodes of motion, corresponding to a plane membrane, produce the characteristics as indicated by the curve. We have studied these types of motion, for somewhat larger cones than
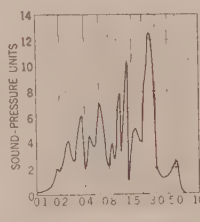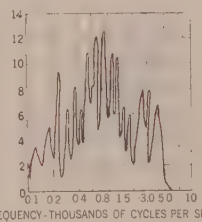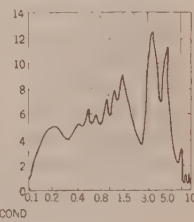
Figs. 4—For the   Fig. 5—For the   Fig. 6—For the
    Year 1924   Year 1924   Year 1925

the 6-in. one adopted by the authors, both theoretically and experimentally, and have found very curious nodes and interesting data which will prove of considerable practical value. At a later date we hope to have the opportunity to present these results.

E. W. Kellogg: Mr. Frederick has called attention to the fact that an inertia-controlled diaphragm implies a low-power-factor system, or one in which force and motion are nearly in quadrature, and therefore only a small fraction of the driving force is expended in the useful work of producing sound radiation. I have made a calculation which indicates that the effi-

ciency of the loud speaker described in our paper is of the order of one per cent, which, it must be admitted is low, but compares very well with that of other loud speakers.

It may be of interest to review the possibilities of a sound reproducer in which the diaphragm motion is in phase with the driving force. Such a condition obtains when a diaphragm is in resonance, and efficiencies of 50 per cent or more are probably possible at a single frequency, using a resonant diaphragm. But when we impose the requirement of substantially constant efficiency over a frequency range of 100 to 5000 cycles, we must forego the benefits of resonance. The resistance-controlled diaphragm will have the correct radiation characteristic, 1—if it is large enough compared with the longest waves to give plane wave radiation, or 2—if it is used with a properly designed horn. For efficiency, the force which resists motion must be due to the air reaction on the diaphragm. In free space this air reaction is very small, and if it is to be large compared with diaphragm inertia or elastic forces, an extremely light and flexible diaphragm must be used. Such a diaphragm must be actuated by a uniformly applied force. Electrostatic loud speakers have been built with large-area diaphragms of very light material, and these have probably had quite high efficiency, if we define efficiency as the ratio of sound power output to electrical power input. But unfortunately we have to pay for the total volt-amperes supplied rather than simply for the electrical power, and the electrostatic loud speaker has a very low electrical power factor.

The case for the horn-type loud speaker has been discussed by Messrs. Hanna and Slepian[1]. By means of the horn the air reaction on the diaphragm can be increased to a point where it will effectively damp the motion of as stiff and heavy a diaphragm as is commonly employed in loud speakers. Thus a magnetically driven diaphragm may be used with resistance-controlled motion, or with a unity-power-factor relation between force and velocity. But a magnetic drive has good efficiency only when the motional impedance is a large part of the total impedance, or in other words, when as in the case of an electric motor, most of the impressed voltage is used in overcoming the counter electromotive force due to armature motion. A study of the motional impedance of magnetic telephones shows that only in the neighborhood of a resonance frequency is the motional impedance considerable compared with the resistance and inductive reactance, and if sufficient damping is introduced by the air reaction on the diaphragm to give substantially uniform response over a wide frequency range, the motional impedance becomes very small at all frequencies. This probably explains the fact that no horn-type loud speaker which we have tested shows any greater average efficiency than our inertia-controlled paper cone. I do not despair of considerably greater efficiencies being ultimately obtained in loud speakers, but from the standpoint of present progress in the art of sound reproduction, I do not believe that the adoption of inertia-controlled diaphragms can be construed as a step in the wrong direction.

Mr. Frederick raised the question of load capacity. The moving-coil drive has a distinct advantage over the iron-armature drive on this score. With the cabinet-set amplifier described in the paper, our loud speaker can easily reproduce vocal solos with the original sound volume, or can reproduce a piano selection as it would be played in a drawing room, though perhaps not with the maximum loudness that would be used in a large concert hall. The limit of loudness is set by distortion in the amplifier rather than in the loud speaker. In fact the latter will handle all the output which can be obtained without distortion from a U. V. 211 radiotron (50 watts oscillator rating) with a 1000-volt plate supply, or eight times the power obtainable from the cabinet-set amplifier.

1. The Function and Design of Horns for Loud Speakers, by C. R. Hanna and J. Slepian, JOURNAL A. I. E. E., March 1924, page 250.

In stating that working with a weak magnetic field makes possible a lower net restoring force in the case of an iron-armature driving element, we made the assumption also made by C. R. Hanna in his January 1925 I. R. E. paper, that the magnetic reduction of stiffness cannot be more than a certain fraction (say 50 per cent) of the spring stiffness.

In comparing two loud speakers, we have rated the one as more sensitive which would produce on the average more total sound output from a given vacuum-tube source, both instruments being equally fitted to the tube impedance. In saying that the moving coil gives greater sensitivity than the iron-armature drive, we are reporting our experience with these types of drive as applied to paper-cone diaphragms.

Mr. McNamee asks about the use of permanent magnets for the field. When the loud speaker is combined with an amplifier, the dynamic field is hardly a drawback since the field winding acts as a necessary filter choke. We have done some experimenting with permanent magnets, but have not, up to the present succeeded in obtaining an adequate field for a moving-coil instrument without a very heavy magnet system.

Mr. Thelin asked about the material of the baffle. It should be stiff and heavy enough so that it will not readily be set in vibration by the air pressure. Wood, pressboard, and similar materials are satisfactory and convenient to use.

The question has been asked whether an iron diaphragm would increase the sensitivity of a Hewlett loud speaker. Dr. Hewlett
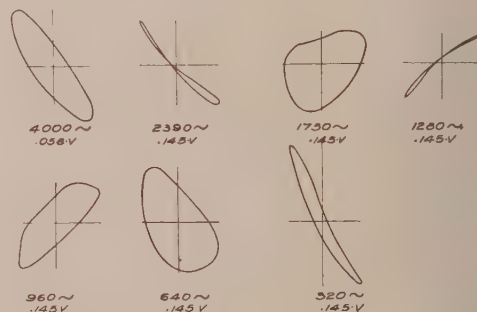
FIG. 7—BRAUN-TUBE RECORDS OF SOUND WAVES

found no gain from the use of iron, but instead, a distinct loss as compared with copper or aluminum. The increased flux density must be around, rather than in, the conductor in order to increase the force.

I am submitting as part of the discussion some sound-pressure curves which we have recently obtained. The measuring arrangements were still in the developmental stage when these curves were taken, and a high degree of accuracy is not claimed. In fact in acoustic measurements so great are the difficulties encountered that a measurement that can be trusted to be within 50 per cent of the correct value might be regarded as highly satisfactory. In the present case a condenser transmitter, with amplifier, detector, and galvanometer, was used for measuring sound pressure. The amplifier, detector and galvanometer system was calibrated by introducing a measured low voltage in series with the condenser transmitter. The condenser transmitter was similar in construction to that described by F. C. Wente in the *Physical Review*, July 1917, and May 1922. A calibration of the condenser transmitter was made by actuating its diaphragm by means of a special, laminated-pole telephone magnet held 1/16 in. from the diaphragm, the force being assumed to be proportional to the current through the coils. This does not give an absolute calibration, but should show any radical departure from the shape of the curve given in the *Physical Review* article already mentioned.

In loud-speaker tests it is important to guard against the error of crediting sound radiated in harmonics to the fundamental frequency. For example, if an instrument is supplied with a 200-cycle alternating current, and it happens to be one hundred times more sensitive at 400 and 600 cycles, than at 200, then a very small percentage of harmonics in the supplied current, plus harmonics produced in the instrument itself may give rise to a much larger radiation of 400- and 600-cycle sound than of 200-cycle sound. If the sound-measuring apparatus measures

FIG. 8—SHOWING SOUND OUTPUT OF LOUD SPEAKER AT DIFFERENT POSITIONS

FIG. 9—CONDENSER TRANSMITTER 34 IN. FROM CENTER OF CABINET. HORIZONTAL DIRECTIVITY OF LABORATORY MODEL OF RICE-KELLOGG LOUD SPEAKER, PER CENT MAXIMUM SOUND PRESSURE VS. ANGLE.

total r. m. s. pressure independent of frequency, considerable sound pressure will be indicated, and this would naturally be assumed to be 200-cycle output pressure.

To make sure that no serious error arose from this source, a Braun-tube oscillograph was set up. Between one pair of plates, a voltage was impressed, proportional to the current supplied to the loud speaker while a voltage from the condenser-

transmitter amplifier, proportional to the sound pressure, was impressed across the other pair of plates of the Braun tube. If both voltages are sine waves, the figure which appears on the screen is an ellipse or an inclined straight line. Harmonics in one of the voltages result in deformations of the figure. In the present measurements, the oscillograph figure was watched throughout the entire range of frequency, and tracings were made of all the figures which were seriously distorted. In no case was it found that the harmonics carried more than 25 per cent of the energy of the fundamental in the output sound wave. Several samples of Braun-tube figures are shown here in Fig. 7.

The next serious problem in the testing of loud speakers results from the fact that the curve of sound pressure vs. frequency, changes in shape with change of microphone position. Which of the many possible positions will give a curve best representing what listeners on the average will hear? It would seem logical to avoid the irregularities due to standing waves in the room, and give a curve in which the sound pressure shown is a measure of the total sound power output. An approximation to this is obtained by averaging the square of the sound pressure over a considerable space by moving the microphone rapidly to and fro during each reading. Facilities for moving the microphone or transmitter in this manner were not available in our case and as an alternative, several curves are shown in Fig. 8 for different transmitter positions. The high or low regions which are common to all three curves may be interpreted as indicating large or small output from the loud speaker, while the irregularities which are different in the different curves are principally room effects. It will be noticed that the curves taken with the transmitter directly in front of the loud speaker show a marked increase in sound pressure above 2300 cycles. The instrument, however, has rarely been criticised on listening tests as having too much high-frequency output. The curve taken with the transmitter to one side, does not show such an excess of high tones. Evidently then the high sound pressures recorded in the upper-frequency range are due in part to the concentration of the sound in a forward beam. The curves of Fig. 9 were taken by moving the transmitter in a circle and recording the sound pressure every 30 deg. They show the radiation at 4000 cycles to be sharply directed forward whereas at 400 cycles there is only a slight depression at the side due to interference between the waves from the front and back of the diaphragm. In total sound radiated, therefore, the excess of high frequencies is only slight. If high frequencies are lost in the transmitting or receiving systems, the listener prefers to take a place directly in front of the loud speaker, so as to get the full benefit of what is left, while if articulation is good, but there are roughnesses, or high-frequency disturbances present in the currents fed to the loud speaker, the listener will sit to one side.

It is probable that the frequency of 2300 cycles, where the forward projected sound begins to increase, marks the transition between the two modes of action of the cone. Below this frequency it acts as a unit or plunger while at higher frequencies there is wave action with some resonances. The depression in the region of 2300 cycles may correspond to the droop in the calculated curve in Fig. 10. This lends support to the belief that practical plunger action is maintained up to 2300 cycles. In the upper range, irregularities in the response may be expected not only from resonance in the cone, but also from the fact that the cone depth is appreciable compared with the sound wave length, and, therefore, the diaphragm no longer radiates like a flat plate.

The loss of output below 200 cycles is due to a decrease in the driving force. If the current through the moving coil is held constant the output sound pressure is practically the same at 80 as at 200 cycles, but in the curves shown here, it is the voltage supplied to the first stage of the amplifier which is maintained constant. The current through the moving coil then changes with changes in the coil impedance. This impedance rises
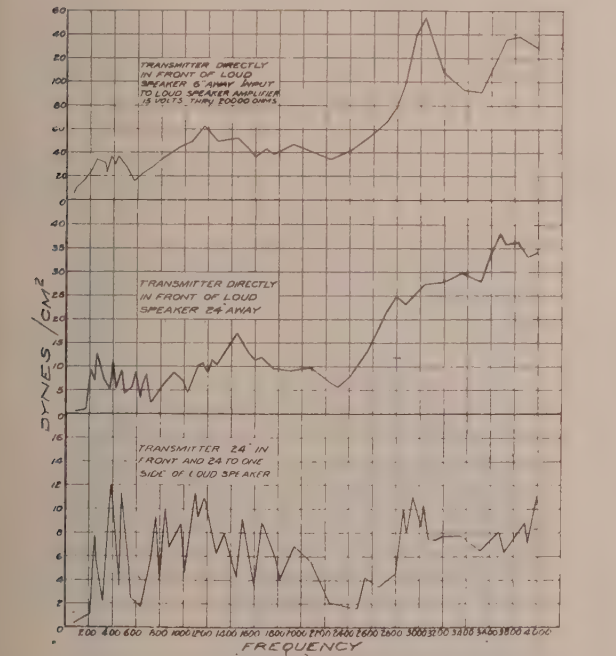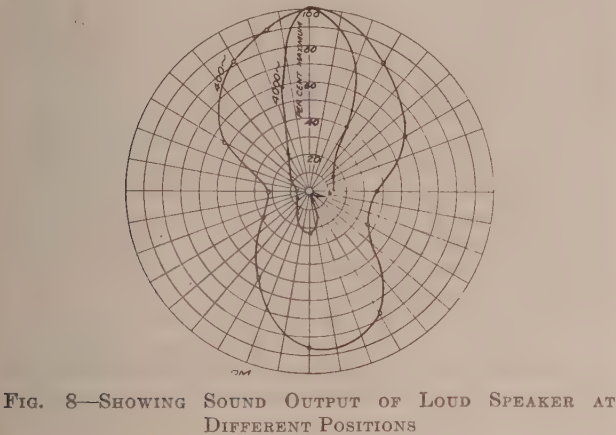
from about 17 ohms at 200 cycles to over 80 ohms at 80 cycles and the consequent decrease in coil current results in reduced driving force and reduced sound output. The rise in impedance is due to the motion of the coil, which with inertia control becomes very large at low frequency.

ELECTRIC SHOVELS[1]
(SHELTON AND STOETZEL)
St. Louis, Mo., April 17, 1925

W. M. Hoen: I think it reasonable to compare the present steam shovel with the development of the mine hoist. The shovel has a little harder job, but it seems to me that in the early days, in electrifying steam hoists, we were up against a difficult proposition. The hoist manufacturers were building and selling steam hoists, so the electrical manufacturer had to furnish equipment which did not do justice to itself. Mine operators also attacked this problem with more or less success. Today the hoist manufacturers have redesigned their equipment as a unit with the electrical apparatus.

Present electrical shovels have done very good work, but the electrical and mechanical parts are not properly co-ordinated. Instead of adding motors to a steam hoist, I think the mechanical parts should be especially designed, and I believe the development of the mine hoist could be profitably utilized.

Those of us who have used the voltage control scheme with shunt motors know that it is unsurpassed for hoisting or intermittent work. It has many advantages where its cost is justified.

The a-c. shovel was the pioneer and has done good work and will continue to be used, possibly on the smaller sizes. It is apparent that on the large shovels, where space and weight are not limited, that the d-c. voltage control system is best adapted for general application.

In replacing present steam shovels with electric, I find that the steam operators are very hard to convert. We cannot offer an electric shovel that will do what the steam is doing, but you will have to do much better. Actual power costs are generally a minor item. In mining work, output within a given time is important. Maintenance, which is generally a big item, is sometimes not considered as against production. Continuity of operation is most important, as a breakdown at a critical time may mean an item far larger than power and maintenance costs combined for a year. Mechanical hoist equipment should be improved, and minor improvements in the electrical equipment will place the electric shovel where it will be far more reliable than the best steam equipment.

Wm. H. Matthews: The Pittsburg and Midway Coal Company at Pittsburg, Kansas, may be numbered among the pioneers in the use of the electric shovel for stripping coal. They have been operating an electric shovel for about eight years. This particular shovel is operated by large induction motors, and to correct the power factor a four hundred and fifty kv-a. synchronous motor is floated on the line all the time the shovel is in operation. I am wondering if the induction motor for power and the synchronous motor for correcting power factor is standard practise on electric shovels manufactured at the present time.

The strip mine that I am discussing uses electricity for stripping the over burden, for loading the coal and for pumping, then they use small steam engines for hauling the coal to the tipple where electrical machinery is again used in the dumping and screening of the coal.

I can see why the steam locomotive would be better than the trolley motor for haulage but I would think that the storage battery motor would give better satisfaction than either. I would like to know if it is standard practice to use steam for haulage around electric shovel plants.

D. J. Shelton: From the standpoint of fuel consumption, the steam shovel, as it stands today, cannot be greatly improved.

Superheat, stokers, piston valves, metallic packings, etc., have been tried, but, generally speaking, an electric shovel of up-to-date design is more economical than the steam machine. The speed of an electric shovel equals that of the steam machines. We have records of the latest steam and electric machines in the same pit and the electric machines show greater output and less cost per cubic yard.

Manufacturers of shovels have tried compounding hoisting engines, but the cycle of duty is such that it is quite impractical, because, when working throttled, the initial pressure in the low-pressure cylinder is too low and increased losses may be the result instead of a saving. When using superheat, maintenance is greater. High temperature, lubrication, packing and the superheater tend to increase maintenance. However, the companies that have tried superheat on shovels like it very much, but as it stands today, there is only one factor that should be considered; that is, the reliability of the electric power supply. Of course, the power rate should be investigated, but when within reasonable limits, it should have little bearing on the final decision.

All the large shovels built use regenerative braking. The empty dipper is lowered on the hoisting motor. This has been practised since 1915.

Mr. Matthews mentioned the big electric shovel near Pittsburg, Kansas. I know this machine is equipped with a-c. motors and it is necessary to provide the synchronous condenser due to the unfavorable conditions established by the a-c. motors being constantly started, stopped, reversed and run at reduced speeds. The a-c. shovel is always likely to be a disturbing factor on a system.

As we see it, and I think I may say as the shovel industry sees it, the proposition may be summarized by saying—The electric shovel is the corect shovel to use if you have reliable power and a reasonable rate, and I think it is a fact established from actual practise that d-c. drive is correct for all shovels.

In discussing electric shovels, one requisite is so often overlooked. The shovel must respond to the operator. While the shovel is a big, clumsy looking thing, it must really be sensitive and respond quickly. Our experience has shown that an operator cannot handle the machines fitted with a-c. equipment, so dexterously as the d-c. machine.

Two factors must be considered when applying electric motors to shovels; one is maximum hoisting pull, and the other is maximum hoisting speed at light loads or when the dipper is empty. The values for these two factors are determined and the gear ratio computed. The disadvantage of the a-c. motor is immediately apparent since it will not run above its normal speed and, therefore, the gear ratio must be small. Then, in order to obtain the maximum bail pull, the motor must be large as compared with either a series motor or a shunt motor operating on variable voltage.

It should be mentioned, that since we may obtain a varying d-c. voltage from motor generators, shunt motors should be considered. This further simplifies matters and I think that all efforts should be made towards the simplification and elimination of parts.

I have mentioned the Ward-Leonard control as applied to the railroad-type and the large revolving shovels. When considering the small shovel, weighing from 60,000 lb. up to 120,000 lb., there is a little different problem. The cost and space available right now will hardly permit the use of Ward-Leonard control on these small shovels. The most efficient shovels are built with three d-c. motors, the hoisting, rotating and crowding devices being independently driven. The supply usually is a-c., so a motor-generator set is provided. The generator voltage is approximately 330 at light load and drops off to approximately 100 volts under maximum load. Rheostatic control is provided and 230-volt motors used. The varying

[1] A. I. E. E. Journal, August 1925, p. 873.

voltage on the generator acts as a buffer and increases the speed range of the motors.

We have shipped shovels equipped with d-c. motors, but without motor-generator sets, the motors being connected directly to a constant-voltage d-c. supply. The operators say "This shovel does not work like the one we saw before purchasing one." They did not have the varying voltage, therefore d-c. to d-c. motor-generator sets were shipped to each of the machines after they operated a short time. In one particular case the shovel output was increased 20 per cent and the cable and gearing maintenance was considerably reduced.

When the first electric shovel was designed, there were two kinds of equipment available. One was the d-c. constant-voltage, contactor control, and the other was the a-c. constant-voltage, contactor control. Several were built with each type of equipment. These shovels, while they were slow, did fairly well, but many difficulties developed; for instance, contactor control is not wholly desirable; there are too many parts, too complicated. The shovel is subjected to being raised and dropped and rotated and abused in many ways, so that a multitude of contactors and automatic relays and complicated control circuit have no place on a shovel.

The series motor more nearly approaches the characteristic of the steam engine than does the a-c. motor. Then, why not use the d-c. series motor? Several shovels were built, but we were continually in trouble with the control system, and we couldn't limit the maximum current. Consider the large shovel that has a bail pull of 100,000 lb. or 1000 amperes on a hoist motor. If the maximum current is permitted to run to 1200 or 1500 amperes, maintenance and power cost will be high with little increase in output.

We found with constant voltage and contactor control that we could not definitely limit the current, and if a device that worked fairly well was provided some fellow would tamper with it and immediately cause it to become inoperative. So we tried to find an equipment that would eliminate all these things and provide the characteristics we wanted. The Ward-Leonard system was the answer; contactors are eliminated, the limiting of the current is automatically done by the drooping voltage characteristic and the combined generator and motor characteristics give a speed-torque curve that is ideal and much better than the steam.

The stored energy in the armature is much greater than that of the reciprocating parts and crank shaft of steam engines. This causes greater strains to be imposed upon the electric shovel. In considering shovel problems, do not overlook the fact that the less stored energy there is in armatures and other moving parts, the better the shovel will operate and the less expense will be required to maintain that shovel.

Mr. Hoen is right when he says the manufacturers of steam shovels formerly struck a motor on wherever they could and used as many steam parts as possible. But that day is past and there is no doubt but that the electrification of the shovel has compelled shovel manufacturers to build a much better shovel, because right in the beginning we found that the designs that would stand up under steam engines would not stand up under electric operation.

Discussion at Swampscott Meeting

OIL-FILLED TERMINALS FOR HIGH-VOLTAGE CABLES[1]
(EBY)
SWAMPSCOTT, MASS., MAY 8, 1925

A. O. Austin (by letter): There has apparently been a material improvement in potheads for high-voltage cable. There is no reason why a pothead cannot be made having any

FIG. 1

desired electrical characteristic, as the problem is not essentially different from making a high-voltage bushing.

The accompanying illustration shows a type of pothead which is quite similar to that shown in Mr. Eby's paper. This pothead was used for running tests on joints and cable for The Cleveland Electric Illuminating Company.

These potheads have an appreciable diameter at the center and form a good reservoir for oil which may be fed into the cable. With potheads of this size it was not possible to flash them over without breakdown of the cable.

In making the tests it was evident that if the cable was free from defects that high frequency had little or no effect. Since high frequency tends to magnify a defect, a much lower voltage may be used and I believe that in the end one of the most valuable cable tests will be that made at high frequency.

If the faulty sections can be eliminated it will be a comparatively easy matter to establish a high degree of reliability. In the potheads shown the stress is reduced to a very low value on the insulation surrounding the cable, as the cable projects up into the bushing. Hence, there is little or no danger of breakdown in the bushing.

The potheads were so designed that it is not necessary to use a wiped joint, as a lead sheath may be clamped to the lower end of the pothead bell using a soft gasket. With this arrangement an installation can be made in a few minutes and there is no danger of damaging the insulation from heat. Pin holes caused by the leaking of oil through the wiped joint are also avoidable.

TEMPERATURE ERRORS IN INDUCTION WATTHOUR METERS[2]
(KINNARD AND FAUS)
SWAMPSCOTT, MASS., MAY 9, 1925

C. H. Ingalls: For the past twelve years, the Meter Division of the Boston Edison Company has corrected for the temperature errors of its portable test meters through thermometers permanently installed in the meters. A recent occurrence illustrates how the accuracy of an uncompensated meter may be affected by certain abnormal temperature conditions.

Two testers were working in the same locality, one of whom went to work directly from home, the other starting from the

1. A. I. E. E. JOURNAL, June 1925, p. 593.

2. A. I. E. E. JOURNAL, Vol. XLIV, March, p. 241.

office. The former kept his test meter in his automobile over night, while the latter's meter was stored in a warm place. This resulted in a difference in temperature of 20 deg. cent. between the two meters at the start of the day's work, corresponding to a difference in the corrections to be applied to the test meters of nearly two per cent. Subsequent tests proved that the thermometers and the applied corrections were correct. It is particularly gratifying that such a simple and positive means of correction for temperature errors can be applied to test meters. The correction of temperature errors at low power factors is not quite as important as the correction at unity power factor, because, with comparatively few exceptions, watthour meters are tested on the system only at unity power factor.

H. E. Knowlton: It might be well to mention that reference to the temperature errors of watthour meters in this paper gives no occasion to the multitude of users of electric service to be disturbed about the situation. I think it is fairly safe to say that they are having that service metered to them with a degree of accuracy not matched by any other commodity service, whether sold by the pound, by the cubic foot or by count. We are dealing here with the minutiae and any layman who chances to read papers of this kind has no reason to be disturbed by our activities in improving electric metering.

I. F. Kinnard: The point brought out by Mr. Ingalls serves to illustrate how a simple and reliable temperature compensation, such as described in this paper, will aid in obtaining precision results in the calibration of watthour meters. As he has indicated, it was hitherto necessary to be sure that test meters were not at abnormally high or low temperatures before using them, in order to obtain the best results. The automatic compensating shunt, however, insures a constant performance over very wide temperature ranges and makes it entirely unnecessary to use thermometers.

As Mr. Knowlton has intimated, the fact that a distinct refinement has been made in the art of watthour-meter manufacture should not in the least shake our confidence in existing meters. If the paper be read carefully it will be seen that errors or variations due to temperature are inherently small in this class of apparatus. It is, however, a distinct advantage to be able to state that temperature will in no way affect the results obtained irrespective of any extreme conditions of use, and it is to that end we are working.

OVER-VOLTAGE ON TRANSMISSION SYSTEMS DUE TO DROPPING OF LOAD[1]
(Burnham)
Swampscott, Mass., May 7, 1925

H. W. Smith: The paper by Mr. Burnham is valuable in that it gives us actual tests on the over-voltages due to overspeeding of waterwheel generators. This problem has also been encountered by the Niagara Falls Power Company who have had lightning arresters fail due to the rise in voltage on dropping of load. Tests have shown that with load suddenly dropped, the generator voltage has increased from 12,000 to 21,000 volts. There was an instantaneous increase up to about 30 per cent above normal voltage. An over-voltage relay has been used to correct this difficulty, and the primary relay of the standard induction feeder regulator has been used as the voltage relay. This relay operates in about ten cycles of a 25-cycle system, and has been set to operate at 30 per cent above normal voltage.

At the Mitchell Dam plant of the Alabama Power Company, the combination of over-voltage and over-frequency relays are used.

W. F. Dawson: There seems to be a difference in practise in respect to waterwheel governing. We in this country do not, so far as I know, provide by-passes to the penstock. Therefore it is necessary to have the governors operate very slowly. Otherwise the inertia of the water column would destroy the penstock.

I do not know how far they have carried the practise but I happened to be in England about eighteen years ago when a prominent London firm was asking for tenders for d-c. generators to be connected with water-wheels at the Lockleven plant of the British Aluminum Company. Following our American practise, I designed the proposed d-c. generators for about 50 per cent overspeed. It is the custom of consulting engineers in this country, to require that generators and water-wheels will be perfectly safe from mechanical overspeed stresses, at the anticipated runaway speed of the water-wheels. I told the consulting engineer that we had made such provision in the machines upon which we were tendering, and he was surprised.

He said, "We do not have to allow for that. Our waterwheel builders provide by-passes about the penstock, so that the governors can operate with sufficient rapidity to prevent overspeeding."

That is the only case I have ever had brought to my attention suggesting that by-passes were provided. If any waterwheel designers are here, we should have information from them, because it is certainly a tremendous handicap to the designers of generators for waterwheel plants, not to speak of the bad effect on over-voltage, to have to provide for from 50 to 75 per cent over-speed.

I realize of course that by-passes mean increased capital account, but the high over-speeding that has to be provided for also means big increase in the cost, not to speak of the disadvantage due to high over-voltage.

H. C. Don Carlos: I should like to correct the impression which might be gained from the last remarks, which intimate that pressure-regulating valves are not commonly used in this country. I think that a large majority of the high-head plants in this country are designed to use relief valves which are operated from the governor mechanically to give a by-pass in the case of heavy load rejections, which would tend to produce a heavy pressure rise in the penstock.

There is another factor which I believe has not been mentioned in the paper or the discussion, which should not be overlooked in a consideration of the over-speed of hydroelectric units, that is, the characteristic of the Francis-type turbine itself, which protects it against an over-speed of more than 65 to 70 per cent. Without any governors at all, most water wheels of this type will not attain an over-speed of more than 65 to 70 per cent on account of the choking of the water in the wheel.

E. J. Burnham: It has been suggested that resistance might be placed in the exciter field, and also in the generator field, in order to check the rise of voltage on a generator that has lost load.

Curve a, Fig. 9, of the paper shows the way generator voltage decreases when resistance is placed in the exciter field circuit. As the resistance in the field circuit is increased Curve a approaches Curve b, as the limit.

The results of inserting resistance in the generator field circuit at the time of dropping load would be represented by a curve lying between Curve b and Curve c, of Fig. 9. The method of inserting resistance in the generator field circuit could easily be adopted in cases where face-plate regulators are used.

Regarding the time of reaching maximum speed, after full load has been dropped, the time of three seconds is not uncommon on waterwheels of ordinary design, as shown by Curve D, of Typical Water Wheel Characteristics, Fig. 16.

The water-turbine characteristic curves shown by Fig. 16 apply, in a general way, to water turbines of different sizes, and used under different conditions, because, taking into consideration the different factors, such as size of turbine, length of penstock, and $W R^2$ of revolving parts, the results will be approximately the same in any case.

In accordance with Mr. Don Carlos' remarks by-passes are commonly used in this country for stations having high heads.

Discussion at Annual Convention

THE QUADRANT ELECTROMETER
(Kouwenhoven)
Saratoga Springs, N. Y., June 25, 1925

J. B. Whitehead: Those of us who have had occasion to measure small values of dielectric loss with the quadrant electrometer instrument, know of the apparent facility and convenience of that instrument. I say "apparent" because we also know that we soon run into many entirely unexpected and apparently inexplicable phenomena in connection with the instrument. In the literature we find a great deal on the instrument and think we will be able to clear up our difficulties. As we go on, however, we find that the points of view of the several people who have written on the quadrant electrometer often differ. The several authors introduce different constants and we are left with a large number of constants, whose relative importance we are unable to determine easily.

I think that Dr. Kouwenhoven has rendered a very important service, in that he has considered the quadrant electrometer from its simplest stage as represented by Maxwell's equations, in which we find every coefficient of induction which is required by a system involving three elements. Some of the constants will change with the deflection of the instrument. The service he has rendered is to show that used as a power instrument many of these constants disappear, either through mutual neutralization or because they happen to be so small as to be negligible. He has thus brought the instrument to a point where it is shown to be reliable through the determination of only two constants; and these two constants can be determined by direct-current measurement.

D. M. Simons: Anyone who has had much practical experience with the quadrant electrometer has found that the so-called constant of the instrument is usually by no means what its name implies; we usually found that the constant would have different values at different voltages, and until certain adjustments were made, it would vary with the magnitude of deflection. It gave one rather a lack of confidence in the fundamentals of the theory of the instrument, because Maxwell's equation was based on the constancy of the proportion between the deflection and the total load. There have been some indications in print that the relationship did not hold good, such as Orlich's article in the *Zeitschrift fur Instrumentenkunde* about ten years ago and the article by Cantutti in *l' Elettricista* in 1923, and the matter has been in the minds of a great many people, without any definite solution. I think, therefore, that Dr. Kouwenhoven is all the more to be congratulated on having solved the question so thoroughly in a quantitative manner.

Personally, I find it rather difficult to mention the quadrant electrometer without discussing the zero method, and the subject is not entirely inappropriate, because one of the main advantages of the zero method is that no knowledge of the constant is required. We described a zero method last year before the Institute,[1] which I believe is very practical, the deflection being brought back to zero merely by the insertion of a resistance in the needle circuit, the value of power factor of the load being calculated in terms of the resistance required. Using any zero method with the electrometer, there are certain great advantages; a straight-line constant is not necessary, and thus there is much greater freedom in the design of the instrument. The setting is practically independent of voltage fluctuations, and thus the measurements may be made much more accurately and quickly than with a deflecting instrument where the needle will swing with every fluctuation of voltage. The reading with the zero method is proportional to power factor, while in the deflection

1. The Quadrant Electrometer for the Measurement of Dielectric Loss, by D. M. Simons and W. S. Brown, A. I. E. E. Journal, December 1924, page 1147.

method it is proportional to watts, and thus the zero method is more suitable for the measurement of ionization.

S. L. Gokhale: 1. To begin with, I suggest that the title of the paper be changed to "Electrostatic Wattmeter;" in the past, all the valuable literature on this subject has been indexed under the head "quadrant electrometer," and it is generally overlooked by those who are searching for information on methods for measurement of power.

2. Tables IV, V and VI constitute a very convincing demonstration of the reliability of this type of wattmeter, for loads of low power factor; but all the cases treated by the author are loads of no distortion. The particular case I am interested in, is the case of core loss in iron for flux density near saturation, involving not only a very low power factor but also a serious distortion of the current wave, with a possibility of distortion of the voltage wave also. It seems to me that the instrument would prove very satisfactory for this purpose also, but I would prefer to have the fact demonstrated, if possible.

3. The question of instrument error, that is, error characteristic of the instrument, irrespective of the nature of the load, is also quite important. On this point, I suggest, by way of experiment, the measurement of core loss in an air-core transformer (*i. e.*, mutual inductor); as there is no real loss to be measured, any apparent loss would obviously be the instrument error. Another experiment directed towards the same end would be the measurement of core loss in iron-core transformers at low flux density by the electrostatic wattmeter, and also by the electro-dynamometer wattmeter.

4. As to the mathematical development of the final working formula (omitting the correction for errors), it may be noted that the author has given two equations, No. (42) and (43). Equation (42) is theoretically the final form in which the variation in the coefficient of torque due to variation in the voltage of the needle has been taken into account. Equation (43), is a simplified practical final form of equation (42), assuming the coefficient of torque to be constant and independent of voltage. In the several experimental demonstrations, given by the author, this coefficient is either really constant, the working voltage having been maintained constant for each series of tests, or practically constant and regarded as such by the author himself. In other words the final working formula is equation (43), not (42). In view of this fact, it may be of interest to know, that equation (43) can be derived directly from the well-known fundamental equation, that is, from equation (11) of Prof. Kouwenhoven, without the intermediate thirty equations which needlessly discourage an average reader. I do not intend to suggest that equation (42) together with the mathematical development which leads to it, is all unnecessary. It is easy to believe that occasions will arise where the nature of the work in hand calls for a variation of voltage, which would make equation (42) indispensable. In view of this possibility, I might suggest, that Prof. Kouwenhoven extend his experiments to the case of varying voltage, other variables being maintained constant for the time. It would be interesting to have it demonstrated, that the coefficient of torque follows the law formulated in equation (42).

W. B. Kouwenhoven: The quadrant electrometer is an electrostatic instrument and measures root-mean-square values exactly. Its readings are independent of wave form and frequency. The capacity-load measurements referred to in Table VI were made with energy supplied from a generator that does not give a pure sine wave. Under these conditions the current wave was badly distorted, nevertheless, the results checked closely. I am sure that the instrument could be successfully used in measuring core loss in iron samples.

As stated in the paper, equation (43) is only a special case of

equation (42). Equation (43) may be directly derived from Maxwell's equation (11).

In using an instrument it is always desirable to have a straight-line constant, but this is not possible in all electrometers for the reasons mentioned in the paper. In some electrometers the constant varies considerably with the needle voltage. In the electrometer referred to in the paper the constant varied as follows:

Needle Voltage						
Needle Voltage	55 volts;	Constant 72	Table V
" "	100 "	" 71.8	" IV
" "	400 "	" 69.7	" VI

This electrometer was used later with voltages as high as 1800 volts on the needle. At this voltage its constant was found to be 33.8. This clearly shows the effect of the variation in voltage upon the constant of the instrument.

A NEW TWO-PHASE TO SIX-PHASE TRANSFORMER CONNECTION[1]
(BOYAJIAN)
SARATOGA SPRINGS, N. Y., JUNE 25, 1925

Vladimir Karapetoff: A general solution of two-phase to six-phase transformation is shown in Fig. 1 presented with this discussion. $O a$, $O b$, $O c$, $O d$, $O f$, $O g$, are six "star" voltages desired to be had on the six-phase side. As a simplest case, imagine a six-phase synchronous motor adjusted to run at unity power factor and used as a load on a two-phase line. Then the foregoing six voltages may be considered, as those across the individual armature phases (star connected) of the motor.
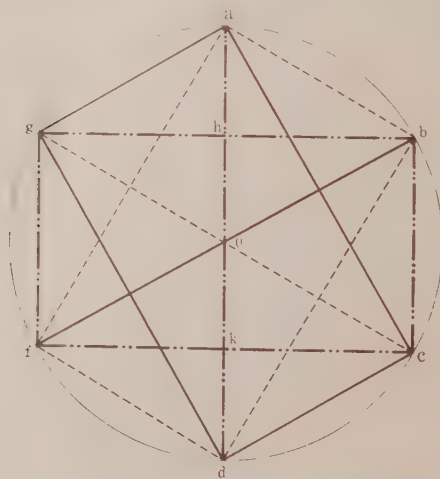

FIG. 1

The problem of phase transformation consists in connecting the vertices of the hexagon by lines of two mutually perpendicular directions. Starting with point a, there are only three possible independent beginnings, viz., $a b$, $a c$, and $a d$. Beginning with $a b$, we have to draw $a b$, $g c$, $f d$, for phase I, and $a f$, $b d$, for phase II. This will give the figure drawn by dotted lines and identical with that shown in Boyajian's Fig. 1.[2] Beginning with $a c$; gives again a Φ figure shown in full lines. Beginning with $a d$, gives an identical Φ figure drawn in "dash and dot." Thus, the Φ transformation is not one of several possible transformations, but the only possible *perfect* transformation.

By a perfect transformation I understand one in which only the vertices of the hexagon are used. With the double-T transformation, auxiliary points, h and k, are necessary, and this causes reactive currents, increased kv-a. rating of the trans-

1. A. I. E. E. JOURNAL, Vol. XLIV, June, p. 591.

2. I suggest calling this kind of transformer connection the "Φ connection," because of some resemblance of the diagram to this Greek letter.

formers, necessity for interlacing, etc. It will be seen from my Fig. 1 that no more lines interconnecting the vertices in a "perfect" way can be drawn; therefore, all possible solutions are included in this figure.

For example, the six-pointed star shown in Boyajian's Fig. 3 may be readily seen in my Fig. 1. It may be of interest to point out that a sketch identical with Fig. 1 was included in the first edition of my "Experimental Electrical Engineering" published in 1909, and the general method of obtaining perfect phase
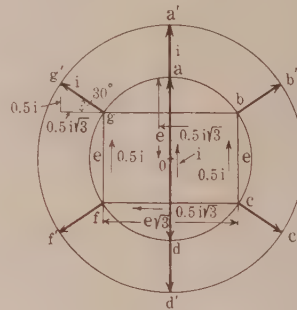
FIG. 2

transformations explained. However, I did not follow the matter any farther and did not realize that I had the Φ figure until I saw it in the paper under discussion.

The reason for which a perfect transformation gives 100 per kv-a. efficiency may be seen in Fig. 2. The six line currents flowing into the load are shown by the vectors $a a'$, $b b'$, etc. The six star voltages are in phase with these currents. Only two voltages, $O a$ and $O d$, are shown. Phase I of the transformer furnishes the currents $a a'$ and $d d'$ directly, and the kv-a. delivered is $2 ie$. The current $g g'$ is furnished by both phases. Phase I supplies 0.51 and phase II supplies $0.5 1 \sqrt{3}$. Thus the phase I furnishes altogether

$$2 i e + 2 (0.5 i) e = 3 i e.$$

Phase II furnishes

$$2 \times (0.51 \sqrt{3}) \times (e \sqrt{3}) = 3 i e.$$

In other words, both phases furnish equal kv-a., and all the
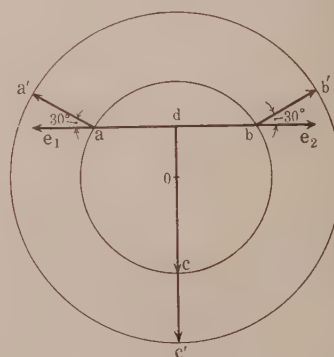
FIG. 3

currents in the transformer windings are in phase with the respective voltages. This means 100 per cent apparatus efficiency.

It will be seen that the Φ connection involves two "stub ends," a and d, and four "junction points," b, c, f, g, where two transformer windings are joined together. For a "perfect" transformation, the stub ends should be used only where the induced voltages in both systems are in phase with each other. At all other points, junctions should be used in order to produce a

resultant current out of two components, each of which is in phase with its induced voltage for that particular transformer case.

It is shown in Fig. 3 herewith that the usual T connection does not satisfy this condition, and for this reason its kv-a. efficiency is less than 100 per cent. Stub ends, a and b, are used in the phases in which the induced voltages differ by 30 deg. As a result, the three-phase currents a a' and b b' are out of phase with the induced voltages when the two-phase side is loaded at 100 per cent power factor. This causes unbalanced magnetomotive forces, increased magnetic leakage, and necessity for interlacing.

Aram Boyajian: Professor Karapetoff has proven for us that the transformer connection here described is the only possible two-phase-six-phase connection of 100 per cent apparatus economy utilizing two-phase fluxes and voltages. If his argument is true, as it appears to be, he saves us from futile effort at further invention along this line.

The connection here described originated in an effort to devise a two-phase-three-phase connection that would be free from the complications and limitations of the Woodbridge connection. Since the Woodbridge connection was based on three-phase flux and voltages, the solution of the problem was sought in the use of two-phase flux and voltages. However, the three-phase system so derived turned out to be a diametric (that is, six-wire) three-phase system, unadaptable to three-wire three-phase systems, and was equivalent to a six-phase system. As stated in the paper, it appears to the author that this is inherent in the nature of things, that is, the derived system has to be diametric, such as four-wire two-phase, or six-wire three-phase. Maybe Professor Karapetoff can definitely prove this to us some time.

THE KELVIN LAW A GENERAL LAW IN DYNAMICS

By Carl Hering

Fellow, A. I. E. E.

The well known and generally accepted law, to the effect that when a circuit does external work it increases its stored or potential energy by an equal amount, called by some the Kelvin law, seems to be only an electrical version of a more general law in dynamics. As the writer showed some years ago, the usual versions (which are man-made and for which nature is not responsible) of the electrical law need some revisions.

As an illustration in ordinary mechanics, let there be a tank of water, A, continuously kept full by a source. Let this tank be connected at the bottom through a water motor to a second but empty tank, B, on the same level. In flowing from A to B, the water will do external work in the motor until it has risen to the level in the tank A. The stored energy in the complete system (tanks A and B) will then have been increased by the potential energy stored in the tank B; this is magnetic energy in the electrical case. Let this energy be W; then the external energy given out by the motor will also be equal to W and the energy from the source will be 2W. Frictionless conditions and a 100 per cent efficiency motor are, of course, assumed.

The correctness of this Kelvin law has recently been questioned by some as it forms the basis of some unexpected results. In principle, however, it seems to be one of the general laws of nature, and if there are any

exceptions to it, they are no doubt due to the wording, which is man-made and, therefore, not infallible.

When there is no external source to keep the tank A full, the electrical analogy would come under the condition of absolute zero of temperature at which the resistance would be zero. A current once started (say by inductance) would continue forever or until the stored energy in its magnetic field is converted into mechanical energy by doing some external work; no additional energy will then be stored thereby. Such a case does not come under the Kelvin law and should therefore be excluded by a proper wording of the law, as shown some years ago by the writer.

The Kelvin law is a relation between three energies under specified conditions; the external energy given off, the stored or potential energy, and the energy supplied to the system by the connected source (excluding that consumed by resistance); the first two are equal and the third is, therefore, double either one of the other two. The conditions, however, should be carefully worded as there seem to be exceptions to all the proposed versions, including the usual "constant current" clause, the striking exception to which is the ordinary electric motor. The above mechanical analogy might help in the proper wording of the electrical version.

ILLUMINATION ITEMS

By the Lighting and Illumination Committee

TWO-FILAMENT HEADLIGHT LAMP MARKS A STEP FORWARD IN AUTOMOTIVE LIGHTING

With the development of the two-filament headlight lamp, as illustrated in Fig. 1, the art of motor-vehicle lighting has advanced a step in the solution of the glare

Fig. 1—The Two-Filament Headlight Lamp Has its Two 21-Candle Power Filaments Spaced 9/64 in. Apart— They are Equally Displaced Above and Below the Lamp Axis

evil. Several new equipments which have been designed for its use, have recently been granted the necessary State approval required before a new headlighting device may be generally applied. Furthermore, several

automobile manufacturers have supplied their new cars with headlight equipment which uses the two-filament lamp.

A review of present practise will make apparent the reason for the new development.

The safest headlighting practise is found in those States in which the system of no dimming prevails, together with device approvals under the specifications sponsored by the Illuminating Engineering Society and Society of Automotive Engineers. The degree of improvement over former conditions has varied with the enforcement machinery and educational effort of the several States. But in all of them, one constantly

A. On Smooth Level Highways

Well designed and properly adjusted fixed beam headlamps provide excellent road lighting without dangerous glare

B. In Approaching over the Brow of a Hill

The high-intensity fixed beam on the left is directed into the eyes of the oncoming driver. The depressed beam of full intensity at the right causes no glare but keeps the road lighted.

C. In Approaching Over Rough Roads

The oncoming driver is subjected to a series of blinding flashes from the fixed beam on the left. With the beam depressed as at the right everyone is safe.

Fig. 2

encounters and hears complaints of glaring lights. Influential newspapers even advocate a return to the dangerous compulsory dimming practise but outstanding figures in the fields of automotive and safety engineering demand that a better solution of the headlight problem be found.

Part of the difficulty is due to the fact that a large number of the head-lamps in service, because of insufficient accuracy either in parts or in the focusing and aiming of the lamps, are not adjusted with the precision implied in the approval specifications. Hence, many of the headlights one meets are always glaring, and others are tilted so far down that they do not light the road sufficiently far enough ahead for safe driving. Even with the best lamps, properly adjusted, the high-intensity part of the beams under certain road conditions, is directed into the approaching driver's eyes and then one is almost forced to dim in passing, accepting whatever hazards this sudden darkening of the road entails.

Fig. 2 shows (a) fixed beams of the approved type, carefully adjusted, giving excellent light on a level road, without unduly interfering with the vision of other drivers. But when, as in (b), cars approach over the brow of a hill or, as in (c), bounce along over a rough road, dangerous glare from fixed beam headlamps as shown from cars on left can only be avoided by dim-
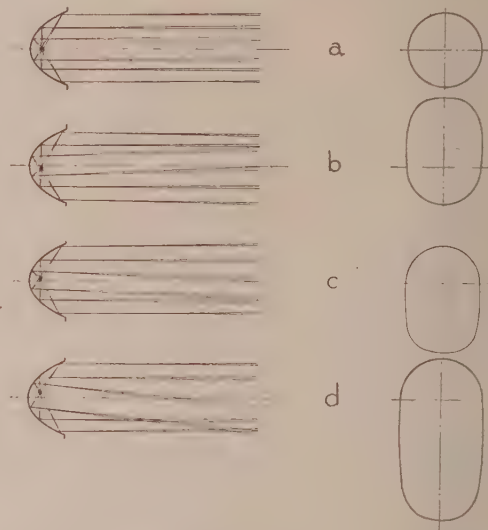
Fig. 3—Light Distribution in Beams from Parabolic Reflector

With a—lamp filament at focus; b—lamp filament below focus; c—lamp filament above focus; d—lamp filament farther above focus

ming. The same is true in turning out on highly crowned roads.

Depressible Beam Solves Problem. What the driver needs is equipment that will permit him, at will, to depress his full intensity beams by tilting them two or three degrees downward. He can then have his lamps normally aimed far enough down the road for safe
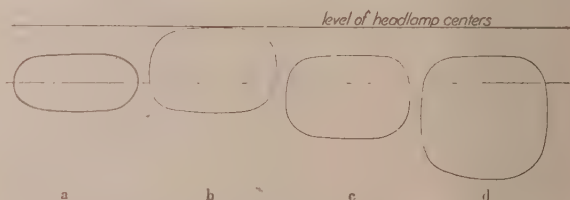
Fig. 4—Light Patterns on Vertical Surface from Beams of Fig. 3 when Spread by Fluted Lens

With top of beam (b) at level of headlamps, a depressed beam is obtained by switching to a filament in positions (a), (c) or (d) of Fig. 3

driving and, at the same time, afford the approaching driver relief under all conditions, as shown by the cars on the right in Fig. 2. The depressed beams light the road brightly for safe passing, yet on lighted streets they meet all the requirements of driving; in fact, once such equipment is in use, the normal practise is to depress the lights for passing cars, even on level roads,

and thus no interference results from that great proportion of beams that could never be accurately adjusted or the adjustment of which has been only slightly affected in driving. The great value of such equipment has long been recognized, but it has not been widely adopted because of the cost and complications of the mechanical and electrical methods employed and the limitations of some of the designs from the lighting standpoint. The two-filament lamp has made it possible to accomplish the desired beam-depression most inexpensively, advantageously, and positively, merely by switching from one filament to the other.

Optical Principles. The simple optical principles that are utilized to produce this result are illustrated in Fig. 3. When the light source is at the focus of a parabolic reflector, the rays are reflected into a narrow beam which, in falling on a screen at right angles to the beam, produces the round spot of light shown at (*a*). If the filament is below the focus, as in (*b*), the spot of light is extended upward into an oval. But if the filament is above the focus, as in (*c*), then the extension is downward and the level of the top of the beam remains unaltered. As the distance from the focus is increased, the distorted beam becomes still deeper, as in (*d*).
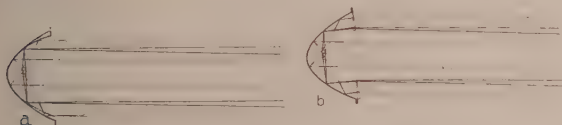
FIG. 5—EXCELLENT LIGHT DISTRIBUTION AND SIMPLEST ADJUSTMENT RESULT WHEN THE REFLECTOR SURFACE OR LENS, OR BOTH, ARE MODIFIED FOR FILAMENTS PLACED AS IN (A) AND (D) OF FIG. 3

Thus, it may be seen that a lamp combining a filament as in (*b*) with a second one as in either (*a*), (*c*) or (*d*), makes possible a controllable beam, depressible at the will of the driver. Equipped with fluted cover glasses to spread the beams, and tilted so as to bring the top of the higher beam, from (*b*), to the level of the headlamps, the relative direction and form of the beams are as indicated in Fig. 4. If a greater angle of tilt is desired, it is necessary only to increase the displacement of the filament below the focus in (*b*). But if the desired angle of tilt is obtained with the filaments spaced at equal distances above and below the focus as in (*b*) and (*c*), then a lamp with filaments separated by the same distance but placed with one at the focus as in (*a*) and the other below by the full amount of the separation, would produce too great a depression of the beam. It has not, in fact, been found commercially feasible to make lamps having a sufficiently small separation of the filaments, to limit the tilt to the desirable two to three degrees when one of the sources is at the focus in headlights consisting of a parabolic reflector and a cover glass with only vertical spreading flutes. The combination of (*b*) and (*c*) must then be used. It happens that with this system, the angle between the two beams is so much affected by

the range of filament position incident to variations in lamps and in socket assembly as to make necessary an additional focusing screw for vertical adjustment. The focusing and aiming of the headlights then obviously becomes somewhat more of a task. These same limitations apply in using the new lamp in the vertically fluted reflectors, as now found on cars.

However, much of present headlighting is done with other classes of equipment, in which reflectors with modified surfaces, or lenses with bending prisms, are employed. These equipments can be made in such a way as to give the most desirable form of controllable beam and still require no provision for vertical adjustment of the bulb and no extra work in focusing and aiming. The reflectors, or lenses, or a combination of the two, can be designed so that the desired angle of tilt is obtained even though the socket is offset to bring one of the filaments on the axis of the reflector. Thus, Fig. 5 (*a*) shows how the modified contour of the reflector directs downward that light which would form the upper part of the beam from the unmodified paraboloid of (*d*) in Fig. 4. At the same time the modified surface can be made to give the most desirable depth of main driving beam from the filament on the axis. In (*b*) of Fig. 5, bending prisms, covering the upper and lower parts of the beam, accomplish similar results. Some equipments of special merit employing these principles have been designed and submitted for approval in connection with the new lamp.

Engineers Favor Depressible Beam. The spacing of 9/64 in. between the two filaments of the new lamp was determined after a thorough study of the best spacing for the various designs of equipment that are being developed or may be brought forth in the future, and the adaptability of the various types to one standard lamp. It is, of course, very important that all equipments be made for this one lamp to insure that, as renewals are needed, the motorist will find only the right one everywhere available. In setting the spacing, a thorough investigation was made of the most desirable angle of depression. If the tilt is made more than three degrees, the depressed beam lights the road insufficiently far ahead. On the other hand, if the angle is less than two degrees, there will be too many situations under which complete relief is not afforded the approaching driver.

NEW YORK-CHICAGO TELEPHONE CABLE

On August 11 at Swanton, Ohio, 19 miles west of Toledo, the last of 9500 splices was made in the New York-Chicago telephone cable, the world's longest telephone cable. The over-all length of the cable is 861 miles, 717 miles being supported overhead by 36,000 poles and 144 miles being underground. It is nearly twice as long as the next longest cable of 450 miles from Boston to Washington. The new cable will, it is expected, be open for service in about a month.

Revised Program for Convention at Seattle, September 15-19

Plans are completed for the Pacific Coast Convention which will be held at the Olympic Hotel, Seattle, Wash., September 15-19. The convention promises to be an excellent one. The technical papers are of very high character and deal principally with transmission, distribution, research and education.

Some changes have been made in the arrangement of the technical sessions on account of the withdrawal of some of the papers. The following program shows the present contemplated schedule which differs from the program published in the August issue of the Journal.

REVISED TENTATIVE PROGRAM FOR PACIFIC COAST CONVENTION

Tuesday, September 15
Forenoon—10:30 A. M.—12:30 P. M.

Address of Welcome—Dr. Henry Suzzallo, President of the University of Washington.
Reports of Committees, etc.

Afternoon—2:00 P. M.—5:00 P. M.

Stored Mechanical Energy in Transmission Systems, by J. P. Jollyman, Pacific Gas and Electric Company.
Spans Having Supports of Unequal Elevations, by G. S. Smith, University of Washington.
The Long Span Across the Narrows at Tacoma, by H. F. Darland and J. V. Gongwer, City of Tacoma.

220-Kv. Transmission Transients and Flashovers, by R. J. C. Wood, Southern California Edison Company.

Evening, 8:30 P. M.

Reception—Dancing.

Wednesday, September 16
Forenoon, 9:30 A. M.—12 Noon

Fundamental Considerations Regarding Power Limits of Transmission Systems, by R. E. Doherty and H. H. Dewey, General Electric Company.
The Line of Maximum Economy, by E. A. Loew and F. K. Kirsten, University of Washington.
Analytical Discussion of Some Factors Entering Into the Problem of Transmission-Line Stability, by C. L. Fortescue, Westinghouse Electric and Manufacturing Company.
Steam Power in Its Relation to the Development of Waterpower, by R. C. Powell, Pacific Gas and Electric Company.

Afternoon

Golf Tournament—Annual Competition for the "John B. Fisken Cup." Open to Pacific Coast members only.
Bridge—Tea for the ladies at the Seattle Yacht Club.
Exhibition of the K-B Boat.
Inspection trip through the mill of the Seattle Cedar Lumber Company.

Evening, 8:00 P. M.

Application of Electric Propulsion to Double-Ended Ferry Boats, by Alexander Kennedy and F. V. Smith, General Electric Company.
Lecture—"*The K. B. Propeller*," by F. K. Kirsten, University of Washington.

Thursday, September 17
Forenoon, 9:30 A. M.—12:30 P. M.

Some New Features and Improvements on the High-Voltage Wattmeter, by J. S. Carroll, Stanford University.
A Stationary Type of Laboratory Standard Wattmeter, by H. V. Carpenter, Washington State College.
On the Nature of Corona Loss, by C. T. Hesselmeyer and J. K. Kostko, Stanford University.
The Study of Ions and Electrons for Electrical Engineers, by Harris J. Ryan, Stanford University.
Engineering Research—A Vital Factor in Engineering Education, by C. E. Magnusson, University of Washington.
Relation Between Engineering Education and Engineering Research, by R. W. Sorensen, California Institute of Technology.
A New Departure in Engineering Education, by Harold Pender, Moore School of Engineering, University of Pennsylvania.

Afternoon, 2:00 P. M.—5:00 P. M.

Distribution-Line Practise of The San Joaquin Light and Power Corporation, by L. J. Moore and H. S. Minor, San Joaquin Light and Power Corporation.
Improvement in Distribution Methods, by S. B. Hood, Northern States Power Company.
The 60-Cycle Distribution System of the Commonwealth Edison Company, by W. G. Kelley, Commonwealth Edison Company.
A High-Voltage Distributing System, by G. H. Smith, City of Seattle Lighting Department.

President's Address
3:30—4:00 P. M.

Dr. Michel I. Pupin, President of the American Institute of Electrical Engineers, will address the Convention over the transcontinental telephone lines.
Twenty-five mile sight-seeing drive around Seattle's beautiful boulevards, for the ladies.

EVENING, 8:00 P. M.

Dinner Dance—Olympic Hotel.

FRIDAY, SEPTEMBER 18

FORENOON, 9:30 A. M.—12:30 P. M.

A Distribution System to Supply Increasing Load Densities in Residential Areas, by M. T. Crawford, Puget Sound Power and Light Company.

Distribution Practises in Southern California, by R. E. Cunningham, Southern California Edison Company.

Power Distribution and Telephone Circuits—Inductive and Physical Relations, by D. I. Cone, The Pacific Telephone and Telegraph Company, and H. M. Trueblood, The American Telephone and Telegraph Company.

Induction from Street-Lighting Circuits—Effects on Telephone Circuits, by R. G. McCurdy, The American Telephone and Telegraph Company.

AFTERNOON, 2:00 P. M.—5:00 P. M.

The Radio Interference Problem and the Power Company, by L. J. Corbett, Pacific Gas and Electric Company.

Opportunities and Problems in the Electric Distribution System, by D. K. Blake, General Electric Company.

Engineering and Economic Features of Distribution Systems Supplying Increasing Load Densities, by L. M. Applegate and Walter Brenton, Portland Electric Power Company.

Tea and a lecture on Chinese Antiques for the ladies.

A. I. E. E. Directors' Meeting

The first meeting of the Board of Directors of the American Institute of Electrical Engineers for the administrative year beginning August 1, 1925, was held at Institute headquarters, New York, on Thursday, August 6.

There were present: President M. I. Pupin, New York; Past-President Farley Osgood, Newark, N. J.; Vice-President A. G. Pierce, Cleveland; W. P. Dobson, Toronto; Managers H. M. Hobart, Schenectady; G. L. Knight, Brooklyn, N. Y.; W. K. Vanderpoel, Newark, N. J.; H. A. Kidder, New York; National Treasurer George A. Hamilton, Elizabeth, N. J.; National Secretary F. L. Hutchinson, New York.

The minutes of the meeting of the Board held June 25 were approved as previously circulated.

A report of a meeting of the Board of Examiners held July 30, 1925, was presented and the actions taken at that meeting were approved. Upon the recommendation of the Board of Examiners, the following actions were taken upon pending applications: 14 Students were ordered enrolled; 102 applicants were elected to the grade of Associate; 8 applicants were elected to the grade of Member; 1 applicant was elected to the grade of Fellow; 18 applicants were transferred to the grade of Member; 3 applicants were transferred to the grade of Fellow.

The Board voted that the date of next year's Midwinter Convention, which, in accordance with the action of the Board of Directors at its June meeting, will be held in New York, shall be February 8-12, 1926; and the President announced the appointment of the Midwinter Convention Committee, as follows: Messrs. H. A. Kidder (Chairman), H. H. Barnes, Jr., G. L. Knight, E. B. Meyer, and L. F. Morehouse.

The appointment of committees for the administrative year beginning August 1, 1925, was announced by President Pupin. (A list of these committees appears elsewhere in this issue.) Representatives of the Institute on various bodies were appointed to succeed those whose terms expired July 31, 1925.

As required by the by-laws of the Edison Medal Committee, the Board confirmed the appointments by the President to the Edison Medal Committee, for the term of five years ending July 31, 1930, as follows: Messrs. George Gibbs, Samuel Insull, and Ralph D. Mershon; and the Board elected the following from its own membership to serve on this committee for the

term of two years ending July 31, 1927: Messrs. W. P. Dobson, Farley Osgood, and A. G. Pierce.

The following Local Honorary Secretaries were reappointed, for the term of two years ending July 31, 1927: Dr. Eiji Aoyago, for Japan; Dr. Axel F. Enstrom, for Sweden; T. J. Fleming, for Argentina; C. le Maistre, for England; Guido Semenza, for Italy. Dr. P. H. Powell was appointed Local Honorary Secretary for New Zealand, to succeed Mr. Lawrence Birks, deceased.

Consideration was given to the appointment of representatives of the Institute on the Assembly of American Engineering Council to succeed those whose terms will expire December 31, 1925, and of an additional representative to which the Institute is entitled by reason of its increase in membership; and the following were appointed for the term of two years commencing January 1, 1926: H. W. Eales, John H. Finney, M. M. Fowler, D. C. Jackson, William McClellan, L. F. Morehouse, M. I. Pupin, E. W. Rice, Jr.

Upon the recommendation of the Standards Committee, the following revised sections of the Institute Standards were approved for adoption as A. I. E. E. Standards: Section 13—Standards for Transformers, Induction Regulators and Reactors (to take effect October 1, 1925); Section 30—Standards for Wires and Cables; and Section 2—Standard Definitions and Symbols.

The recommendation having been made by the Section delegates at Saratoga Springs, June 22, that a committee be appointed to consider present policies and procedure regarding the various Institute prizes and any recommendations for such changes as may be deemed desirable, and inasmuch as other matters not considered by the Section delegates have been suggested for consideration relative to the present Institute prizes, the Board voted that the President be authorized to appoint a Special Committee on Institute Prizes, to consider all suggestions that have been received, and to make recommendations, regarding policies and procedure in connection with all Institute prizes, including national, regional, and Enrolled Student prizes.

In connection with the meeting of the National Nominating Committee which is required by the Institute by-laws, the Board voted that the budget for the year beginning October 1, 1925, include a provision for the payment of traveling expenses of the members of the National Nominating Committee, at the rate of ten cents per mile one way from the homes of the members to the meeting place.

Other matters of importance were discussed, reference to which may be found in this and future issues of the JOURNAL.

Power and Mechanical Engineering Exposition

The fourth National Exposition of power and mechanical engineering will be held at Grand Central Palace, New York City, from November 30th through December 5th, 1925.

The "Power Show," as the exhibit is called, is intended to prove an important clearing house of information for all industries.

As usual, the annual meetings of The American Society of Mechanical Engineers and the American Society of Refrigerating Engineers will be held during this same week, and their programs will allow of ample opportunity to visit the exhibits.

Fall Meeting of the American Welding Society

On October 21-23 inclusive, the American Welding Society will hold its Fall meeting in Boston.

Plans are already practically completed to make this meeting the largest and most successful the Society has ever held. Exhibits of welding, as well as actual demonstrations in welding

and cutting, will be featured and five technical sessions upon subjects important to the utility of the art are scheduled.

Headquarters will be at the Massachusetts Institute of Technology and it is expected that 20,000 people, including some of the leading industrial executives of the northeastern United States, will be present. On Tuesday evening, a dinner and theater party will be given, at which the ladies attending will be the guests of the Society. Wednesday evening will also be given over to entertainment and all welders in New England are invited to attend. Copy of complete program will be sent upon request to the Secretary, M. M. Kelly, 33 West 39th Street.

Fourteenth Annual Congress of the National Safety Council

The tentative program for the Safety Congress to be held in Cleveland, Ohio, September 28 to October 2, 1925 gives much for anticipation. There is no doubt but that this coming meeting will be the greatest safety gathering ever held, and the exhibit of safety devices will be most comprehensive and interesting.

Association of Iron and Steel Electrical Engineers Convention

All efforts are being directed towards two major features; First— Technical Sessions.
Second—Iron and Steel Exposition.
The Technical sessions this year will embrace the subjects of Safety, Oil Circuit Breaker Maintenance, Frog Leg Windings, for Direct Current Motors, Electric Heat Treating Furnace applications. The operation of Electrically Heated Soaking Pits, Electric Melting Furnaces, Auxiliaries and Auxiliary Drives for Steam Electric Generating Stations, Extending the Heat Cycle in boiler Operation by the use of Preheated Air for Combustion.

The convenience and comfort of all guests will be carefully provided for.

International High-Tension Conference

Work covered by the 1925 session of the *Conference Internationale des Grands Reseaux Electriques* was, in outline, as follows:

The Conference Internationale des Grands Reseaux Electriques held, during the month of June last, its third session, in which 25 countries participated.

This Conference studies all the questions connected with the production of electric energy, the construction of high tension lines and the operation of large net-works: it constitutes therefore a source of documentation of exceptional importance.

The Transactions of this session will consist of two volumes of 1100 pages each. But in view of the considerable expense which the printing of these volumes represents, it is necessary to receive at least 1000 subscriptions.

Persons who desire to make sure of securing a copy of these Transactions are asked to send without delay their order to the Conference Internationale des Grands Reseaux Electriques, 25, Boulevard Malesherbes, Paris, accompanying this order with a sum of 200 francs which represents the purchase price of the volumes.

Arrangements for Chemical Exposition Program

The program of speakers for the intensive one-week course in chemical engineering fundamentals for college students, to be held in conjunction with the Tenth Exposition of Chemical Industries, Sept. 28th to Oct. 3rd at the Grand Central Palace, New York, is gradually nearing completion. Some of the leading

authorities in their respective fields in the chemical industry and associated groups, will lecture at the Students' Course at the Chemical Exposition.

Three general addresses on the chemical industry, chemistry in all industry, and the buying and selling of chemicals will be given. Dr. Charles H. Herty, president of the Synthetic Organic Chemical Manufacturers' Association will speak on "The American Chemical Industry;" Dr. Arthur D. Little on "The Application of Chemistry to Industry;" Williams Haynes on "Buying and Selling the Products of Chemistry."

Addresses on special phases of chemical engineering practise will be given as follows: "The Commercial Application of the Disintegrating Mill" by Pierce M. Travis of the National Homogenizer Corporation; "Separation of Solids from Liquids—Filtration, Grading, Classifying and Thickening" by Arthur Wright of the Filtration Engineers, Inc.; "Screening, Grading and Classifying" by Albert R. Reed of W. S. Tyler Company; "Handling of Materials—Intraplant Transportation" by A. E. Marshall of the Corning Glass Works; "Ceramics in the Chemical Plant" by Ross C. Purdy, secretary of the American Ceramic Society; "Heat Resisting Alloys" by Arlington Bensel of Victor Hybinette, Inc.; "New Developments and Operations in Thickening and Clarification" by Noel Cunningham of the Hardinge Company; "Liquids and Their Centrifugal Separation" by W. D. Cleary of the De Laval Separator Company; "Dryers and Drying" by F. E. Finch of the Ruggles Coles Engineering Corporation; "Conveying with Steel Belting" by James S. Pasman of Sandvik Steel, Inc.; "Pyrex Glass" by A. E. Marshall of the Corning Glass Works; "Emulsions and Emulsification" by Pierce M. Travis of the National Homogenizer Corporation; "Lacquers as a Protective Coating" by Arthur Orr of the Commercial Solvents Corporation; "Bakelite" by T. S. Taylor of the Bakelite Corporation.

The speakers scheduled thus far represent about half of the finished program for the Students' Course, it being planned to add almost an equal number of additional well-known speakers before completion of the full program. A number of leading engineers have been scheduled tentatively, and definite announcement of their addition to the program will be made later. The Course is open to all college students in chemistry or chemical engineering, or others in the industry who desire to go over a one week's course in the fundamentals of chemical engineering. Lectures will be held each morning of the Exposition at the Grand Central Palace.

No charge is made to those who attend.

Progress with Survey of Air Transportation

Following the announcement that a survey of air transportation would be undertaken jointly by the Department of Commerce and the American Engineering Council, the executive secretary of the Council, L. W. Wallace, issued a statement of progress.

Pointing out what has been accomplished, and what it is purposed to accomplish, Mr. Wallace declares that the Council is realizing the essential aims visualized by its founders. Not only in national but in international effort, he asserts, is the Council winning influence.

A Radio Handbook

A new book, published in German by Verlag von M. Krayn, (1925, 337 pages, cloth) is a work dealing principally with the subject of radio from the popular broadcasting point of view with chapters on antennas, detectors, theory of transmission, loud speakers, vacuum tubes, etc.

It is well written and well illustrated; probably of greater value to those desiring to construct radio receiving sets than to the research engineers.

Revised Sections of A. I. E. E. Standards

The following revised sections of the Standards are now available:

No. 1   General Principles upon which Temperature Limits are Based in the Rating of Electrical Machinery (20 cents).

5   D-C. Generators and Motors and D-C. Commutator Machines in General (40 cents).

7   Alternators, Synchronous Motors and Synchronous Machines in General (40 cents).

8   Synchronous Converters (40 cents).

11   Railway Motors (30 cents).

14   Instrument Transformers (30 cents).

15   Industrial Control Apparatus (40 cents).

34   Telegraphy and Telephony (30 cents).

36   Storage Batteries (20 cents).

37   Illumination (30 cents).

38   Electric Arc Welding Apparatus (40 cents).

41   Insulators (30 cents).

42   Symbols for the Electrical Equipment of Buildings (20 cents).

A discount of 50 per cent is allowed to members of the A. I. E. E.

New Honors Group in Electrical Engineering at M. I. T.

A selected group of students who have stood high in the first two years of their electrical engineering course at the Massachusetts Institute of Technology will, beginning with the next academic year (that is when they enter upon their junior work), be given the privilege of greater independence of work than is usual in an engineering school curriculum.

This freedom from existing restrictions of class and laboratory hours will afford a much larger opportunity for reading and study relating to the subjects under consideration in the term. In order that the students' progress may be orderly and any difficulties encountered may be courageously faced and overcome, a conference of an hour and a half each week will be held between the group and a member of the Faculty learned in the subjects for the term, in which conferences the progress or the difficulties will be discussed mutually. Substitution of subjects in the curriculum will also be provided to accommodate particular tastes and interests of the students.

A different conference adviser will be assigned for each term during the junior and senior years, enabling the group to become intimate with the modes of thought and learning of a number of the Faculty members. At times when special features may be discussed in the conference, the specialists for which the Institute staff is notable will be invited to attend and take part in the mutual discussions, thereby giving opportunity for farther enlargement of the students' acquaintance with members of the staff and of the students' horizon of thought.

The students will thus be placed largely upon their own responsibility in respect to study in the text books, the libraries, and the laboratories, but will be kept in touch with the progress of their own class through the conferences, and the conferences will also be used for the purpose of inspiration and encouragement of the individual students in their work. It is believed that by this process the students will be able to easily pass the usual term examinations in the subjects and that they will be gratified in securing a broader grasp than is common in the usual classroom work.

PERSONAL MENTION

C. C. Stewart of the Oklahoma Gas & Electric Company at Drumright has been appointed manager of the Norman offices of that company.

B. R. Amsden has entered the services of the Malden (Mass.) Electric Company, one of the properties of Charles H. Tenney & Company of Boston.

H. A. Triplett has resigned from the Duquesne Light Company of Pittsburgh to become affiliated with Schweitzer & Conrad Company, Inc., Chicago.

John F. Maxwell has become associated with the Edison Electric Illuminating Company of Boston. Mr. Maxwell was formerly with Stone & Webster, Inc.

G. H. Bucher, Assistant General Manager of the Westinghouse Electric International Company, has recently sailed for Japan to assist in the organization of the newly formed Westinghouse Electric offices in that country.

A. J. Houghton, Jr., formerly with the Engineering Department of the Southern California Edison Company at Los Angeles has left to join the Department of Water and Power, Bureau of Power and Light for the City of Los Angeles.

H. V. Putman has resigned his position as Assistant Chief Engineer of the Ideal Electric and Manufacturing Company of Mansfield, Ohio, and is now connected with the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa.

Dr. W. D. Coolidge of the Research Laboratory of the General Electric Company has been elected to life membership in the National Academy of Sciences in recognition of his development of the Coolidge X-Ray Tube, which has been of such value in the field of roentgenology.

F. F. Espenschied, who has been representing the Commercial Electric Truck Company and the Electric Machinery Manufacturing Company of Pittsburgh for some years, has removed to Philadelphia, where he will manage, for the former concern, the Philadelphia territory sales office.

B. E. Anderson has recently become electrical engineer in charge of the electrical erection at the Kings River project of the San Joaquin Light and Power Corporation, near Fresno Calif. Mr. Anderson was formerly with the Great Western Power Company at Berkeley, California.

A. B. Gibson, formerly manager of the Westinghouse Technical Night School, has been appointed manager of the Development and Supply Division of the Railway Sales Department of the Westinghouse Company. Mr. Gibson has written a number of articles for magazines on personal problems.

Charles F. Goob, by an ordinance of the City Council of Baltimore, has been appointed head of the Mechanical-Electrical Service, one of ten bureaus under the Department of Public Works of that city. The Electrical Commission of Baltimore, of which Mr. Goob was chief engineer, has been abolished, by the provisions of this measure.

Frank J. Meyer of the Oklahoma Gas & Electric Company has recently been made assistant to the general manager in charge of operations. Mr. Meyer entered the employ of this company in 1902 as an apprentice and has served in the capacities of chief electrician, superintendent of the gas department, electrical engineer and general superintendent, respectively.

John L. Crouse, Manager of the Development and Supply Division of the Railway Sales Department has been appointed Assistant to the Manager of Railway Department, both positions being in the East Pittsburgh offices of the Westinghouse Electric and Manufacturing Company. Mr. Crouse has been with this corporation for thirty-two years and has held his previous position for the past five years.

WILLIAM J. MILLER has resigned from the University of Arkansas where he served as electrical and mechanical research engineer in the engineering equipment station to accept the position of Dean of Engineering at the Texas Technical College, Lubbock, Texas. This new college will open its doors to students on October 1st of this year, offering among other engineering courses one in textile engineering.

H. G. SCOTT, has resigned from the vice-presidency of the Columbia Gas & Electric Company. Mr. Scott will assume the chairmanship of the board of directors and the executive committee of the Serval Corporation. Mr. Scott's record as a builder of properties is well known, the remodeling of Nitro, West Va., from a deserted ammunition manufacturing center into the present flourishing industrial town, being one of his achievements.

RAY PALMER, president and general manager of the New York & Queens Electric Light and Power Company, has resigned to engage in Consulting Engineering with offices in New York and Chicago. Mr. Palmer has always taken an active part in the Queensboro Chamber of Commerce and other civic organizations. During the World War he was chairman of the Committee on War Industry, serving as regional commissioner for Queens on the War Industries Board.

PAST SECTION MEETINGS

Atlanta
Dinner and Annual Meeting. The following officers were elected: Chairman, W. E. Gathright; Vice-Chairman, H. N. Pye; Secretary-Treasurer, W. F. Oliver; Directors, E. H. Ginn and E. Van Hook. July 15. Attendance 20.

Lynn
Preparation of Refined Oils and Gasoline by E. S. Candor, The Texas Company. The following officers were elected: Chairman; E. D. Dickinson; Vice-Chairman, D. F. Smalley; Secretary-Treasurer, F. S. Jones. Refreshments were served. June 11. Attendance 104.

Niagara Frontier
Some Problems in Telephone Engineering, by H. L. Davis, American Telephone and Telegraph Company. June 5. Attendance 35.

Panama
New Automatic Telephone System, by J. K. Barrington, Automatic Electric Co. The following officers were elected: Chairman, Lester W. Parsons; Vice-Chairman, Charles F. MacMurray; Secretary-Treasurer, I. Franklin McIlhenny. Dinner was served. July 7. Attendance 18.

Philadelphia
June Outing with the Affiliated Societies of the Engineers Club of Philadelphia, held at Cedarbrook Country Club. June 10. Attendance 350.

Seattle
The Baker River Hydroelectric Development by E. N. Robinson, Illustrated with slides. The following officers were elected: Chairman, E. A. Loew; Secretary-Treasurer, C. E. Mong. May 20. Attendance 81.

Southern Virginia
Fuel Conservation and Its Relation to Highway Design,
Safety Methods in Handling Oil and Gas, by L. G. Bentley,
The Electrical Industry and Its Use of Oil and Gas, by W. C. Bell,
Fuel Oil and Fuel-Oil Plants, by E. C. Wiley,
Diesel Type Engines, by L. W. Jackman, and
Gas as an Industrial Fuel, by C. B. Phillips. Joint meeting with A. S. M. E., A. S. C. E. and A. A. E. April 24. Attendance 38.
Richmond Problems of Sewerage and Drainage, by T. T. Towles, Assistant Director of Public Works,
The Petersburg Viaduct, by F. P. Turner, N. & W. Ry., Roanoke, Va.
Civil Engineering, by Professor C. M. Spofford, Massachusetts Institute of Technology,
Address by Robert Ridgway, President, A. S. C. E.
Power Development at Niagara Falls, by Geo. S. Anderson, Niagara Falls Power Co. Joint meeting with A. S. C. E., A. S. M. E. and A. A. E., with morning, afternoon and evening sessions on May 8 and excursions and recreation on May 9. Attendance 32.

Utah
Annual Meeting. The following officers were elected: Chairman, John Salberg; Secretary-Treasurer, Daniel Lee Brundige. July 18. Attendance 146.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES AUGUST, 1925

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

ELECTRICITY AND THE STRUCTURE OF MATTER.
By L. Southerns. London, Oxford University Press, 1925. (The World's Manuals). 128 pp., illus., diagrs., 5 x 7 in., cloth. $1.00.

The first section of this book gives a slight sketch of the history of the subject up to the discovery of the electron. The historical method is then abandoned; and, after consideration of a few important older applications of electricity, an account is given of several of the principal theoretical and practical developments, such as radio-activity, atomic architecture, electromagnetic waves and atomic aggregates. The book is a good popular account, suitable for the general reader.

WHO'S WHO IN ENGINEERING, 2nd edition. 1925.
By John William Leonard. N. Y., Who's Who Publications, Inc., 1925. 2483 pp., 10 x 6 in., cloth. $10.00.

The second edition shows marked improvement over the first, particularly in size. Nearly one thousand pages have been added, and the book now contains brief biographies of over eighteen thousand members of the engineering profession. The majority of these men are residents of North America, but there

are also a considerable number from other countries. In addition to the alphabetical arrangement, a geographical index is supplied. The preface states that a conscientious effort has been made to include only names that are representative of the best in engineering.

System of Physical Chemistry, v. 2; Thermodynamics. Ed. 4.

By William C. McC. Lewis. N. Y., Longmans, Green & Co., 1925. (Text-books of physical chemistry). 489 pp., tables, 9 x 6 in., cloth. $4.75.

In this edition the opportunity has been taken to make further corrections and emendations and also to introduce short accounts of recent investigations of the applications of thermodynamics to chemistry.

Sound, Light, Electricity and Magnetism.

By William Ballantyne Anderson. 2nd edition. N. Y., McGraw-Hill Book Co., 1925. (Physics for technical students). 821 pp., illus., diagrs., 9 x 6 in., cloth. $2.50.

A general textbook in which the practical side of the subject is emphasized. Intended for a first course in college physics, particularly for students of engineering and agriculture. The new edition has been carefully revised. ·

Plane and Spherical Trigonometry.

By Claude Irwin Palmer and Charles W. Leigh. Ed. 3, enl. N. Y., McGraw-Hill Book Co., 1925. 221 pp., + 136 pp., tables, 9 x 6 in., cloth. $2.50.

A textbook in which those parts of trigonometry which are necessary to a proper understanding of the courses taken in schools of technology are emphasized. Included in the volume is the author's "Five-Place Logarithmic and Trigonometric Tables."

The new edition is revised and partly rewritten.

Iron and Steel in the Industrial Revolution.

By Thomas Southcliffe Ashton. Manchester, University Press, 1924. (Publications of the University of Manchester, Economic History Series, No. 11.) 265 pp. illus., 5 x 8 in., cloth. $5.00.

A history of the rise and development of the English iron industry between the years 1700 and 1815. The author describes the early charcoal-iron industry, the discovery of smelting with coke and of cast steel, the changes brought about by the steam-engine, and the invention of puddling and rolling. The effects of overseas competition and England's commercial policy before 1776 are discussed, as is the influence of wars on the iron industry. Chapters are devoted to combinations of capitalists, to labor and to the ironmasters. The author's chief interest is with the economic development rather than the technical.

Jahrbuch des Reichsverbandes der Automobilindustrie. 1925.

By Curt Sperling and Ernst Valentin. Berlin, Ernst Valentin Verlag, 1925. 496 pp., illus., 10 x 6 in., cloth. 14-gm.

This yearbook of the German automobile industry contains a statistical review of trade conditions during the past year, and a number of articles on technical problems. Among the topics treated are fuel feed systems for trucks, automobile testing, the correct principles of carburetor design, the use of light metals in automobile construction, standardization, structural materials, wheel and tire design, heavy oil engines for trucks, electric trucks, and electrical equipment. Other articles discuss trade conditions in Austria, the economics of automobile operation, foreign import duties, the trucking methods of Berlin, the Berlin omnibus system, electric trucks and delivery cars, automobile fire-fighting apparatus, and the automobile equipment of the national postal service. In addition, there is a vocabulary of approved technical terms and a collection of formulas, tables, etc.

Heat Engines, Steam, Gas, Steam Turbines and Their Auxiliaries.

By John R. Allen and Joseph A. Bursley. Ed. 3. N. Y., McGraw-Hill Bk. Co., 1925. 422 pp., illus., diagrs., tables, 6 x 9 in., cloth. $4.00.

An elementary treatise based on the course given at the University of Michigan. Only those engines are considered which are in common use, and the use of the calculus and higher mathematics has been avoided.

The forms of heat engines discussed include the steam engine with its boiler plant, the gas engine with its producer, oil engines and steam turbines. This edition has been rewritten to a large extent.

Effective Regulation of Public Utilities

By John Bauer. N. Y., Macmillan, 1925. 381 pp., 6 x 8 in., cloth. $2.50.

The purpose of this book is to consider critically the existing policies and methods by which the regulation of public utilities has been attempted; to show the inadequacy and deficiency of the existing machinery; and to suggest constructive measures for a realization of the fundamental purposes of regulation. It aims to give the accountants, engineers and lawyers interested in the subject a clearer, more vivid understanding of what is involved in regulation and what is needed to make it effective. The author has been engaged in regulation for fifteen years and is public utility consultant to the Corporation Counsel of the City of New York.

A Course of Metallurgy for Engineers.

By F. C. Thompson. Lond., Witherby, 1925. 240 pp., illus., diagrs., tables, 6 x 9 in., cloth. 27s 6d net.

Discusses the composition and structure of the metals used in engineering, the defects in ingots, heat treatment, the changes induced by hot or cold working, case-hardening, etc. The text is confined to iron, steel, brass, bronze, aluminum alloys, and bearing metals. The text is compressed, yet readable, and is intended for the user of forgings and castings rather than for the maker.

Costruzioni Elettromeccaniche . . . . v. 2, sez., 2a. Ed. 3.

By Ettore Morelli. Torino, Unione Tipografico-Editrice Torinese, 1925. 1417 pp., illus., diagrs., plates, 10 x 6 in., paper. $4.00.

A third, thoroughly revised edition of that portion of Professor Morelli's elaborate treatise which treats of transformers, direct and alternating current motors, converters and various special machines. The treatment is unusually detailed and covers both design and construction, so that the work is useful as a guide to current Italian practise, as well as for purposes of instruction.

Automobiltechnisches Handbuch, hrsg. von Richard Bussien. Ed. 11, Berlin, Krayn, 1925. 1106 pp., illus., tables, 6 x 8 in. cloth, 24 gm.

A handbook for automobile engineers and designers, prepared by a board of editors for the German Society of Automobile Engineers. Covers the field of current practise in the usual fashion of engineering handbooks, giving the numerical data and the formulas usually required, describing the design and manufacture of the various parts and giving standards. In addition to gasoline cars, the book contains information on electric vehicles, automobiles for special purposes, motorcycles, motor plows and marine engines.

Engineering Societies Employment Service

Under joint management of the national societies of Civil, Mining, Mechanical and Electrical Engineers as a cooperative bureau available only to their membership, and maintained by contributions from the societies and their individual members who are directly benefited.

MEN AVAILABLE.—Brief announcements will be published without charge and will not be repeated, except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York City, and should be received prior to the 15th of the month.

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case and with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

STATISTICAL ENGINEER, capable of organizing and managing a statistical department in a growing public utility. Reply by letter stating experience, education, age, starting salary expected and send photograph. Location, New York. R-6773.

ENGINEER, 30-35, for editorial staff of a leading technical journal. Should be experienced in the installation and operation of power plants and in meeting and dealing with men in important positions. Must be able to write good English and know the requirements of good English construction. State experience, age and salary expected in first letter. Location, Illinois. R-7031.

TECHNICAL GRADUATE, young electrical engineer. Several years' experience preferred in connection with electric shovels and dredges of all sizes, alternating current, direct current and Ward Leonard equipment. Opportunity. Location, Wisconsin. R-6415.

ENGINEER AND PATENT ATTORNEY, having knowledge of electricity, chemistry and electron physics for development and patent work on vacuum and similar devices, with large corporation. Analytical ability, good judgment and tact essential. Apply by letter stating education, experience, age and salary expected. Location, East. R-6794.

ENGINEER, 35-40, who has had executive and sales experience who can invest $5,000 to $10,000 in an electrical business. Location, New York. R-5456.

INSTRUCTOR, mechanical engineering graduate preferred. Apply by letter stating experience and salary desired. Location, New York. R-7196.

ELECTRICAL ENGINEER, experienced on design of sub-stations and generating stations, large capacity and high voltage. Apply by letter giving experience, nationality and salary expected. Location, eastern Pennsylvania. R-7191.

MEN AVAILABLE

PLANT ENGINEER, recently connected with one of the largest confectionary plants in the United States, experienced in the installation and operation of electrical, mechanical, steam and refrigeration equipment. Desires a connection where he could be of service in a similar or other industry. Available upon reasonable notice. C-186.

ELECTRICAL ENGINEER, B. S. in chemistry and B. S. and M. S. in electrical engineering, three years' electrical experience; one year test and two years development work with the General Electric Company. Prefers developmental work

or position with consulting engineer. Location immaterial. C-211.

COLLEGE GRADUATE, ten years' varied experience in testing, construction, teaching and utility. Wants consulting engineering connection in the Pacific Northwest. Available upon a month's notice to present employer. A-4216.

ASSISTANT EXECUTIVE, position desired by production engineer, twenty years' experience in tool, experimental and instrument line, five years of which as foreman experimental work and radio. Thoroughly conversant with handling help efficiently and producing actual results. Education general science and electrical engineering. Excellent references. Location, greater New York. B-2798.

TECHNICAL GRADUATE, electrical engineer, single, age 29, five years' experience in testing, construction, some operating, drafting and design of substations and transmission systems. Wishes position offering further advance in substation design or construction office. Foreign graduate, speaks English fluently. Knowledge European languages. Location, preferably vicinity of New York City. B-8043.

ELECTRICAL ENGINEERING GRADUATE, 28, one and one-half years' experience in Berlin, and one and one-half years on test with large manufacturing concern, desires to change position to New York. Very adaptable and a hard worker. B-9775.

ELECTRICAL ENGINEER, technical graduate, age 34, married, desires position as engineer of distribution or service maintenance. Seven years' experience in design and operation of transmission and distribution systems with large electric service companies. Prefer East or Middlewest. Available on sixty days' notice. B-6703.

ENGINEER, age 37, married, over fifteen years' experience industrial and power plant organization, design and operation; transmission, group substations, layout, equipment, valuation, costs. Has some financial backing to interest in a conservative utility. Full time salary $7500. Available September. Location, in or about New York and the East. B-8863.

ELECTRICAL ENGINEER, age 27, technical graduate, desires position with manufacturer electrical apparatus. Five years' experience with large company manufacturing industrial control equipment. Minimum salary $2500. Available on reasonable notice. B-6274.

ASSISTANT EXECUTIVE, technical graduate, age 29, desires employment as engineer assistant, or chief clerk for the general manager, or owner of a manufacturing, engineering or opera-

ting firm. Has had several years of executive experience and desires to obtain a position with an older person who has a personal interest in his assistants. C-245.

ELECTRICAL ENGINEERING GRADUATE, 1924, one year's experience in the building and testing of large electrical equipment with an American manufacturer noted for his products. Desires work in maintenance department of manufacturing concern. Location preferred, Michigan or Ohio. B-8472.

RADIO ENGINEER, age 23, technical education, unmarried and now employed, desires change. Development of apparatus or of radio communication systems preferred. Location immaterial. Minimum salary $3000. C-189.

ELECTRICAL ENGINEER, university graduate, age 36, married, desires position as superintendent electrical department with large industrial plant, or mining operation. Wide experience in supervising installation, operation and maintenance of equipment in industrial plants, coal and metal mining. Available on reasonable notice to present employer. B-9113.

ELECTRICAL ENGINEER, age 26, single, graduate E. E., has had two years' experience on lighting and control circuits, eighteen months' on General Electric Company Test, six months' general office experience with the same company, also six months' electrical inspection work. Location preferred, Pennsylvania, New York or the East. B-9090.

SUPERINTENDENT OF ELECTRICAL CONSTRUCTION, age 41, single, twenty years' experience supervising electrical construction, maintenance and operation. Speaks English and Spanish. Available on reasonable notice. Latin-America preferred. B-9642.

ELECTRICAL DESIGNER AND ENGINEER, technical man, widely experienced on power plant and high tension indoor and outdoor substation layouts; capable of supervising and checking work, only position requiring first-class man desired. Married, age 30. C-292.

ELECTRICAL AND MECHANICAL ENGINEER, graduate with honors, G. E. Test, Switchboard and Central Station Engineering departments, experienced shops, drafting, design and layouts, H T transmission and protective gear, desires operating experience with power company. Available October. Location immaterial. B-7623.

GRADUATE ELECTRICAL ENGINEER, with an unlimited chief engineer s marine license, testing experience with General Electric Company, and some experience in system operating department of large public utility. Desires position in

generation or operation department of a public utility or manufacturing company where there is an opportunity for advancement. Available immediately. Location immaterial. B-7947.

ELECTRICAL ENGINEER, technical graduate, experienced in mechanical and electrical design of single-phase, polyphase and direct current motors, desires position with firm manufacturing motors. Broad experience in experimental and development work. Available on reasonable notice. Age 35, married. B-9395.

ELECTRICAL ENGINEER OR SUPERINTENDENT, technical training, wide experience in installation, operation and maintenance of heavy electrical machinery, cranes, etc., in large industrial plant. Position desired East or New England. C-285.

ENGINEERING ASSISTANT, E. E., age 30, single, with practical experience of one year in drafting and one year in distribution with a Public Utility, desires a connection with a central Station,

a Public Utility Company or a Railroad Company. Available at two weeks' notice. Location preferred, East. B-8782.

ELECTRICAL ENGINEER, age 38, leading man, self reliant, broad worker, 15 years technical and commercial experience in all branches of electric engineering, working knowledge of Spanish, wishes position of responsibility for American concern next spring. Available at once. B-8609.

RECENT GRADUATE, member of A. S. M. E. and A. I. E. E., 28, single. Recent graduate in electrical and mechanical engineering desires a position with good experience and a chance for advancement. Location immaterial. Willing to accept foreign service in the future. Available now. C-294.

ELECTRICAL AND MECHANICAL ENGINEER, member A. I. E. E., 40, married. Technical University graduate, 15 years' of practical experience in the design, test and construction of

electric machines, switch-board panels (controllers). AC and DC, elevator and hoisting machinery and their installations. Available after two weeks' notice. Location, New York. B-5240.

ENGINEER, 20 years' experience, chief engineer, electrical engineer, superintendent for chemical plants, electric furnace plants. Familiar with plant design, drafting room practise, plant construction and equipment as well as operation and maintenance. B-6891.

EXECUTIVE of unusual experience, Director of Research and Development Engineer. Thoroughly trained in theory, practise, and business of development and manufacturing. Ability in handling men with continuous record of achievement. Graduate and post graduate degrees, Fellow and Senior Member of three National Engineering Societies, Electrical, Mechanical, Chemical. Minimum salary $12,000. Location with major part of time in New York City preferred. Available upon 30 days' notice. C-320.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED AUGUST 6, 1925

ADLER, WILLIAM M., Electrical Draftsman, The Bronx Gas & Electric Co., 43 Westchester Square, Bronx, New York. N. Y.

ALAUDDIN, R., Chargeman, Electrical Power House, G. I. P. Railway Works, Jhansi, U. P., India.

ANDERSON, GEORGE H., Sales Engineer, General Electric Co., 387 Main St., Springfield, Mass.

*ANDERSON, LOUIS IRVING, Specification Engineer, Commonwealth Edison Co., 72 West Adams Sts., Chicago, Ill.

ARAI, TAKEHARU, Electrical Engineer, Daido Denryoku K. K., Nagoya; for mail, Daido Denryoku Momoyama Power Station, Agematsu, Nishichikuma-gun, Nagano-ken, Japan.

ASAI, TOKUJIRO, Electrical Engineer, Mitsubishi Electrical Engineering Co., Kobe, Japan.

BAUS, RALPH A., Chief Electrician, Penn Allen Cement Co., Nazareth, Pa.

BEWLAY, W. CRAWFORD, Factory Manager & Vice-President, The Electric Products Co., Cleveland, Ohio.

BLANCHARD, R. I., Sales Engineer, Toledo Edison Co., Maumee; res., Perrysburg, Ohio.

BLEACKLEY, ROBERT, Repair Engineer & Electrician, City of Swift Current, Sask., Can.

BOSSEMEYER, C. OWEN, Asst. Superintendent, Elec. Distribution, Pacific Gas & Electric Co., 83 S. 3rd St., San Jose, Calif.

BULL, CHARLES BEEKMAN, Estimator, Brooklyn Edison Co., 360 Pearl St., Brooklyn; res., New York, N. Y.

CALABRESE, GIUSEPPE, Electrical Draftsman, Engg. Dept., New York Edison Co., 23rd St., New York; res., Brooklyn, N. Y.

CALLAHAN, CHARLES PRESTON, Field Engineer, A. G. Mfg. Co., 1350 Dearborn St., Seattle, Wash.

CANADY, JOSEPH CHARLES, Westinghouse Elec. & Mfg. Co., Chicago, Ill.

CARICATI, VINCENT, Draughtsman, 3529 Barnes Ave., Bronx, New York, N. Y.

*CARLSON, ARTHUR W., Electrical Engineer, Murrie & Co., 47 E. 17th St., New York; res., Brooklyn, N. Y.

CHARTERS, JOSEPH SOUZA, Draftsman, Engg. Dept., New York Edison Co., 44 E. 23rd St., New York, N. Y.

*CHUTTER, GEORGE ALBERT, Engineer, Industrial Engg. Dept., General Electric Co., Schenectady, N. Y.

CLARK, STANLEY MAXWELL, Electrician, Union Gas & Elec. Co., Cincinnati, Ohio.

*CRAMER, LORA P., Graduate Student, Educational Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.; for mail, Martinsville, Ind.

CROCKER, ARTHUR WILBUR, Patent Examiner, U. S. Patent Office, Washington, D. C.; res., Clarendon, Va.

DANNE, HAROLD ALEXANDER, President, Electric Smelter & Machine Co., 41 Park Row, New York, N. Y.

DAWBARN, DAVID INGLIS, Sales & Engg. Representative, A. Reyrolle & Co., Hebburn, Eng.; for mail, Milwaukee, Wis.

DEARDORFF, RALPH WARNER, Engineer, Pacific Tel. & Tel. Co., San Francisco; for mail, Berkeley, Calif.

DRESEL, RUDOLPH, Draftsman, Electric Surveys, Pacific Gas & Electric Co., 17th & Clay Sts., Oakland, Calif.

DRON, ROBERT, Electrical Contractor, 403 Madison Ave., Madison, Ill.

*DRURY, THOMAS JOSEPH, Printing Press Man, Star Publishing Co., 232-239 William St., New York; res., Brooklyn, N. Y.

*ERICKSON, GEORGE L., Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

EWASZEWSKI, ADAMS S., Protective Relay Inspector, Westinghouse Elec. & Mfg. Co., Plant St., Newark; res., Harrison, N. J.

FIELDS, WILLIAM STERLING, Supervisor of Tests & Power Distribution, American Rolling Mill Co., Ashland, Ky.

*GARLOCH, GERALD LYNN, Transformer Designing Engineer, Westinghouse Elec. & Mfg. Co., Sharon, Pa.

GIEDD, ROBERT H., Illuminating Engineering, Northwestern Public Service Co., General Office, Huron, S. Dak.

GILLERN, MAURICE FRANK, District Manager, Sierra Electric Co., Inc., 443 S. San Pedro St., Los Angeles, Calif.

GJERME, REIDAR, Electrician, Ohio Power Co., 305 Cleveland Ave., Canton, Ohio.

GRAINGER, AUSTIN HOWARD, In charge of Electrical Dept., W. H. Alexander, May St., Belfast, Ireland.

*GRAY, ALEXANDER WALLACE, Student, Pratt Institute, Brooklyn, N. Y.

GRIFFITH, R. T., Senior Engineering Assist. Bell Telephone Co. of Pa., 416 7th Ave., Pittsburgh, Pa.

HARRINGTON, GEORGE FRANCIS, Electrical Engineer, Supply Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

HAUTEBERQUE, PETER JOSEPH EUGENE, Engineer, Bell Telephone Laboratories, 463 West St., New York, N. Y.

HEIMAN, HOWARD O., Student, School of Engineering, Milwaukee, Wis.; res., Van Orin, Ill.

HERBRUCK, WILLIAM M., Consulting Engineer, 918 15th St., N. W., Canton, Ohio.

HOLLEY, MILTON EMMERSON, Laboratory Tester, Philadelphia Electric Co., 23rd & Market Sts., Philadelphia, Pa.

HURLEY, JAMES FRANCIS, Technical Inspector, Brooklyn Edison Co., Pearl & Willoughby Sts., Brooklyn, N. Y.

ILARIA, ALFREDO, Electrical Draughtsman, Hugh L. Cooper & Co., Wilson Dam, Ala.

JACKSON, ROBERT HUGH MILBOURNE, Student Engineer, New York Edison Co., 55 Crosby St., New York, N. Y.

*JOHNSON, ERNEST E., Electrical Engineer, General Electric Co., Bldg. No. 2, Schenectady, N. Y.

JONES, ROY CHANDLER, Development Engineer, Bell Telephone Laboratories, Inc.; Hawthorne Sta., Chicago, Ill.

KATTENS, J. P., Student, Engineering School of Milwaukee; 229 10th St., Milwaukee, Wis.

KEAST, PHILIP, Mechanic, Empire Mines, Grass Valley, Calif.

*KEITH, JOHN MONROE, Field Engineer, Public Service Production Co., 86 Park Place, Newark, N. J.

KIRKWOOD, GORDON BRUCE, Sales Engineer, Pacific Electric Mfg. Co., 5815 Third St., San Francisco; for mail, Los Angeles, Calif.

KORFF, WILLIAM, Supervising Engineer, Transmission Engg. Dept., Southern California Edison Co., 433 S. Olive St., Los Angeles, Calif.

LAGERQVIST, GOTTFRID, Draftsman, E. Y. Sayer Engg. Corp., 202 N. Calvert St., Baltimore, Md.; for mail, c/o American Society of Swedish Engrs., 271 Hicks St., Brooklyn, N. Y.

LANG, HENRY THOMAS, Chief Engineer, Electric Vacuum Cleaner Co., Ivanhoe Rd., East Cleveland; res., Cleveland Heights, Ohio.

LATTING, WALTER EDWARD, Inspector, Elec. Engg. Dept., Elec. Construction Bureau, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

*LEFEVER, PAUL M., Electrical Inspector, Philadelphia Electric Co., 1000 Chestnut St., Philadelphia, Pa.

LUDASY, AKOS, Switchboard Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., Wilkinsburg, Pa.

LYDEN, JOSEPH M., Erecting Engineer, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

MANNING, ANDRES C., Chief Electrician, Hawaiian Philippine Co., Silay Hawaiian Central, Negros Occ., P. I.

MARTEN, CLARENCE A., Salesman, Western Electric Co., Inc., 84 Marion St., Seattle, Wash.

MATHEWS, JOE R., Manager, Kentucky Power Co., Inc., Augusta, Ky.

MAYNARD, ROGER DANIEL, Meter Test Foreman. Public Service Electric & Gas Co., 17th & Stevens Sts., Camden, N. J.; for mail, Paoli, Pa.

MEACOCK, JOHN HARPER, Chief Designer, Express Lift Co., Ltd., London, S. W. 1; for mail, Westminster. London, Eng.

MORECOCK, EARLE M., Instructor, Mechanics Institute, Rochester, N. Y.

MURPHY, WALLIS CALDWELL, Electrical Foreman, McIntyre Porcupine Mines, Ltd., Schumacher. Ont.. Can.

MUTTHERSBOUGH, WILLIAM ARD, System Operator, Pennsylvania Power & Light Co., Williamsport, Pa.

PHINNEY, EDWARD DANA, Junior Examiner, U. S. Patent Office, Washington, D. C.; for mail, Clarendon, Va.

*POTTS, JULIAN CORTLANDT, Switchman, New York Telephone Co., New York; for mail, Brooklyn, N. Y.

PRIGOHZY, THEODORE ADOLPH, Elec. Engr., Service Dept., Freed-Eiseman Radio Corp., 40 Flatbush Ave. Ext., Brooklyn, N. Y.

QUINBY, EDWIN JAY, Apparatus Design Dept., Western Electric Co., Inc., 463 West St., New York, N. Y.

*RAFSNIDER, LOWELL BRUCE, Engineer, Cincinnati & Suburban Bell Telephone Co., 225 E. 4th St., Cincinnati; for mail, Toledo, Ohio.

RASMUSSEN, OSCAR, Switchboard Operator, Commonwealth Edison Co., 3200 E. 100th St., Chicago, Ill.

RAWLINGS, M. J., Engineer, Trans. & Dist. Dept., Philadelphia Electric Co., 23rd & Market Sts., Philadelphia; res., Cynwyd, Pa.

RIDER, JOHN EDWARD, Appraisal Engineer, Murrie & Co., New York; for mail, Brooklyn, N. Y.

ROBERSON, JAMES ROSS, Supt. of Construction, Puget Sound Power & Light Co., 3030 Colby Ave., Everett, Wash.

*RODRIGUES, JOHN ROZARIO, Electrical Charge Man, B. B. C. I. Railway, Rutlam; for mail, Tardeo, Bombay, No. 7, India.

ROGOFF, JOSEPH, Industrial Engineer, Salto Textile Co., Kossuth St., Bridgeport, Conn.

ROUGE, F. K., Electrical Engineer, Electric Products Co., Cleveland, Ohio.

RUSSELL, RICHARD E., Dist. Plant Superintendent, American Tel. & Tel. Co., 230 Grand River Ave., E. Detroit, Mich.

SALGADO, ANTONIO RAMON, Electrical Tester, Crocker-Wheeler Co., Ampere; res., East Orange, N. J.

SANTMYER, GEORGE W., Charge of Construction Work for Frank R. Sweeney, Connellsville, Pa.

SELLERS, ORVAL E., Teacher, Practical Electricity, Board of Education, Grace School, Akron, Ohio.

*SENIOR, ARTHUR H., Superintendent, Feeder Dam, Hydro-Electric Station, Glens Falls, N. Y.

SINGH, BHAI MAN, Electrical Engineer, Sub-Division Project, Public Works Dept., Raisina, Delhi Prov., India.

SLAMAN, L., Manager, Murdo Electric Co., Murdo, S. Dak.

SPRINGER, HAROLD E., Electrical Draftsman, Stone & Webster, Holland Bldg., Seattle, Wash.

*STRAY, GEORGE ROSE, Student Engineer, Testing Dept., General Electric Co., Schenectady, N. Y.

TAKANO, SHIRO, Electrical Engineer to the Ministry of Communication, Peking, China.

*THOMPSON, ALLAN KERR, Mech. & Elec. Designing & Drafting, Westinghouse Elec. & Mfg. Co., 420 S. San Pedro St., Los Angeles, Calif.

TROWBRIDGE, HAROLD VICTOR, Farm Manager, Willamina, Ore.

TYLER, B. OTTO, Chief Electrician, Associated Oil Co., Coalinga, Calif.

VAN ANTWERP, GEORGE STEWART, Supt. of Distribution & Transmission, The Counties Gas & Electric Co., 120 W. Penn St., Norristown. Pa.

WATKINS, GEORGE WESLEY, Foreman, Standardizing Laboratory, General Electric Co., West Lynn; for mail, East Lynn, Mass.

WELSOME, PETER JOSEPH, Electrical Draftsman, Hugh L. Cooper & Co., Inc., Wilson Dam. Florence, Ala.

WILLHOFFT, F. O., Sec.-Treas., T. H. Goldschmidt Corp., 15 William St., New York, N. Y.

YAMADA, MAHIRO, Electrical Engineer, Elec. Dept., Daido Denryoku K. K.; for mail, Maegasu, Yatomicho, Amagun, Aichi-ken, Japan.

YOUNG, JOHN FARQUHAR, Engineering Assistant, Kilburn & Co., Fairlie Place, Calcutta, India.

YOUNG, LEONARD BROWN, Edison Lamp Works of General Electric Co., 123 Spring St., Atlanta, Ga.

YOUNG, WILLIAM WALLACE, JR., Tester, New York Edison Co., 92 Vandam St., New York. N. Y.; res., Woodridge, N. J.

Total 100

*Formerly Enrolled Students

ASSOCIATES RE-ELECTED AUGUST 6, 1925

HANDLEY, HARRISON KENNETH, Design Engineer, Dallas Power & Light Co., Interurban Bldg., Dallas, Texas.

McANGE, W. N. JR., President & Treasurer, Inter-Mountain Telephone Co., Bristol, Tenn.

MEMBER RE-ELECTED AUGUST 6, 1925

CAMPBELL, FRED R., General Manager, Campbell X-Ray Co., 17 Stewart St., Lynn, Mass.

MEMBERS ELECTED AUGUST 6, 1925

ETHERIDGE, HAROLD LOWELL, Engineer, Stone & Webster, Inc., 147 Milk St., Boston, Mass.

FALKINER-NUTTAL, GEORGE ROBERT, Electrical Engineer, Great Western Power Co., 530 Bush St., San Francisco, Calif.

GILSTON, JACOB, Vice-President, Edwards Electrical Construction Co., 70 E. 45th St., New York, N. Y.

GOULD, MORTIMER D., Manager, Engg. Div., Westinghouse Elec. & Mfg. Co., 814 Ellicott Sq., Buffalo, N. Y.

MILLER, EUGENE HERBERT, Manager, Switchgear & Meter Depts., The Edison Swan Electric Co., Ltd., Ponders End, Middlesex; for mail, Enfield, Middlesex, Eng.

RICHARDS, EARL M., Vice-President, H. O. Swoboda, Inc.; Pittsburgh; res., Beaver, Pa.

WYNNE, THOMAS NEIL, Vice-President & Chief Engineer, Indianapolis Light & Heat Co., 48 Monument Place, Indianapolis, Ind.

FELLOW ELECTED AUGUST 6, 1925

MONROE, WILLIAM S., President, Sargent & Lundy, Inc., 1412 Edison Bldg., Chicago, Ill.

TRANSFERRED TO GRADE OF FELLOW AUGUST 6, 1925

HART, PERCY E., Chief Engineer, Toronto Hydro-Electric System, Toronto, Ont.

HOUSKEEPER, WILLIAM G., Member of Technical Staff, Bell Telephone Laboratories, New York, N. Y.

SKIRROW, JOHN F., Vice-President, Director & Chief Engineer, Postal Telegraph Cable Co., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER AUGUST 6, 1925

BARROW, CHARLES J., Consulting Engineer, Albany, N. Y.

BLACKWOOD, WILLIAM C., Electrical Engineer, New York & Queens Electric Light & Power Co., Flushing, N. Y.

BULL, EDMUND W., Superintendent of Light & Power, City of Regina, Regina, Sask.

CRAWFORD, PERRY O., Vice-President & Chief Engineer, California Oregon-Power Co., Medford, Ore.

DYSON, WALTER, Consulting Electrical Engineer, Tampa, Fla.

FICK, CLARENCE W., Northwest Engineer, General Electric Co., Portland, Ore.

GORDON, CHESTER S., Engineer, Dept. of Development & Research, American Tel. & Tel. Co., New York, N. Y.

GREVES, GEORGE L., Assistant Professor of Electrical Engineering, University of California, Berkeley, Calif.

HAWKER, CLIFFORD F., Electrical Engineer. E. W. Clark Engineering Corp., Columbus, O.

HORRELL, CHARLES R., Sales Manager, Sangamo Electric Co., Springfield, Ill.

JUDSON, CLARENCE H., Engineer, Outside Plant Methods, Pacific Tel. & Tel. Co., San Francisco, Calif.

LEILICH, FRANK T., Engineer, Consolidated Gas & Electric Co., Baltimore, Md.

MARSHALL, STEWART M., Consulting Engineer, Perin & Marshall, New York, N. Y.

MERCER, GEORGE G., Assistant Professor of Electrical Engineering, Lafayette College, Easton, Pa.

MURPHY, JOHN J., President & Engineer, Electric Construction & Machinery Co., Rock Island, Ill.

PHILP, GORDON O., Superintendent, Niagara Falls District, Hydro-Electric Power Commission, Niagara Falls, Ont.

SHARLAND, G. A., Chief Electrician, Minnesota By-Product Coke Co., St. Paul, Minn.

WORCESTER, THOMAS A., Electrical Engineer, General Electric Co., Schenectady, N. Y.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meetings held June 15 and July 30, 1925, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

TO GRADE OF FELLOW

AUSTIN, ARTHUR O., Manager and Chief Engineer, Ohio Insulator Co., Consulting Engineer, Ohio Brass Co., Barberton, O.

BENNETT, CHARLES E., Electrical Engineer, Georgia Railway & Power Co., Atlanta, Ga.

DUBILIER, WILLIAM, President and Technical Director, Dubilier Condenser and Radio Corp., New York, N. Y.

JOHNSON, CARL E., Vice-President & Secretary, U. S. Electrical Mfg. Co., President, U. S. Industries, Inc., Los Angeles, Calif.

TO GRADE OF MEMBER

VAN DEVENTER, HARRY R., Vice-President, Dubilier Condenser and Radio Corp., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before September 30, 1925.

Andrews, J. W., Florida Citrus Exchange, Tampa, Fla.

Caldwell, J. A., Consolidated Textile Corp., Lynchburg, Va.

Clancy, J. A., Jr., Gray Electro Chemical Lab., Inc., Bayonne, N. J.

Cleghorn, R. R., Baltimore Copper S. & R. Co., Canton, Baltimore, Md.

Den Hartog, J. P., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

Dirks, V. F., Electric Light Commission, Lansdale, Pa.

Erb, W., Southern Bell Tel. & Tel. Co., Atlanta, Ga.
(Applicant for re-election.)

Etienne, L. A., Westinghouse Elec. & Mfg. Co., St. Louis, Mo.

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Name	Chairman	Secretary
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Boston	W. R. McCann	W. H. Colburn, 39 Boylston Street, Boston, Mass.
Chicago	Carl Lee	K. A. Auty, Room 1000, Edison Building, Chicago, Ill.
Cincinnati	H. C. Blackwell	E. S. Fields, Union Gas & Electric Co., Cincinnati, Ohio
Cleveland	Chester L. Dows	J. F. Schnable, Elec. Controller & Mfg. Co., Cleveland, Ohio
Columbus	R. J. B. Feather	W. T. Schumaker, 25½ North High St., Columbus, Ohio
Connecticut	A. A. Packard	A. E. Knowlton, Dunham Laboratory, Yale University, New Haven, Conn.
Denver	V. L. Board	R. B. Bonney, Telephone Building, P. O. Box 960, Denver, Colo.
Detroit-Ann Arbor	G. B. McCabe	Harold Cole, Detroit Edison Co., 2000 Second Ave., Detroit, Mich.
Erie	H. J. Hansen	L. H. Curtis, General Electric Co., Erie, Pa.
Fort Wayne	E. L. Gaines	D. W. Merchant, General Electric Co., Fort Wayne, Ind.
Indianapolis-Lafayette	V. T. Mavity	J. B. Bailey, 48 Monument Circle, Indianapolis, Ind.
Ithaca	J. G. Pertsch, Jr.	Geo. F. Bason, Cornell University, Ithaca, N. Y.
Kansas City	F. S. Dewey	Henry Nixon, 509 Mutual Building, Kansas City, Mo.
Lehigh Valley	W. H. Lesser	G. W. Brooks, Pennsylvania Power & Light Co., Allentown, Pa.
Los Angeles	C. A. Heinze	R. A. Hopkins, 420 S. San Pedro St., Los Angeles, Calif.
Lynn	E. D. Dickinson	F. S. Jones, General Electric Co., Lynn, Mass.
Madison	L. E. A. Kelso	Leo J. Peters, University of Wisconsin, Madison, Wis.
Mexico	D. K. Lewis	E. F. Lopez, Fresno No. 111, Mexico, D. F., Mexico
Milwaukee	H. R. Huntley	L. F. Seybold, 446 Public Service Building, Milwaukee, Wis.
Minnesota	A. G. Dewars	J. E. Sumpter, 940 Security Building, Minneapolis, Minn.
Nebraska	P. M. McCullough	C. W. Minard, 509 Electric Building, Omaha, Neb.
New York	H. A. Kidder	H. V. Bozell, Bonbright & Co., 25 Nassau St., New York, N. Y.
Niagara Frontier	J. Allen Johnson	A. W. Underhill, Jr., 605 Lafayette Building, Buffalo, N. Y.
Oklahoma	E. R. Page	A. D. Stoddard, Box 382, Bartlesville, Okla.
Panama	L. W. Parsons	I. F. McIlhenny, Box 413, Balboa Heights, C. Z.
Philadelphia	Nathan Shute	R. H. Silbert, 2301 Market St., Philadelphia, Pa.
Pittsburgh	G. S. Humphrey	W. C. Goodwin, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Pittsfield	E. D. Eby	C. H. Kline, General Electric Co., Pittsfield, Mass.
Portland, Ore.	L. W. Ross	J. C. Henkle, Hawthorne Building, Portland, Ore.
Providence	W. P. Field	F. N. Tompkins, Brown University, Providence, R. I.
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St. Louis	Fred D. Lyon	Ralf T. Toensfeldt, 311 City Hall, St. Louis, Mo.
San Francisco	R. C. Powell	A. G. Jones, 807 Rialto Building, San Francisco, Calif.
Schenectady	W. J. Davis, Jr.	W. E. Saupe, Bldg. No. 41, General Electric Co., Schenectady, N. Y.
Seattle	E. A. Loew	C. E. Mong, 505 Telephone Building, Seattle, Wash.
Southern Virginia	H. B. Hawkins	E. W. Trafford, 1030 W. Franklin St., Richmond, Va.
Spokane	G. S. Covey	Richard McKay, Washington Water Power Co., Lincoln & Trent, Spokane, Wash.
Springfield, Mass.	R. P. King	J. Frank Murray, 251 Wilbraham Ave., Springfield, Mass.
Syracuse	W. C. Pearce	L. N. Street, College of Applied Science, Syracuse University, Syracuse, N. Y.
Toledo	A. H. Stebbins	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio
Toronto	L. B. Chubbuck	W. L. Amos, Hydro-Elec. Power Commission, 190 University Ave., Toronto, Ont.
Urbana	C. A. Keener	J. T. Tykociner, 300 Electrical Laboratory, University of Illinois, Urbana, Ill.
Utah	John Salberg	D. L. Brundige, Utah Pr. & Lt. Co., Box 1790, Salt Lake City, Utah
Vancouver	A. Vilstrup	C. W. Colvin, B. C. Elec. Railway Co., Hastings St., Vancouver, B. C.
Washington, D. C.	A. F. E. Horn	L. E. Reed, Potomac Elec. Pr. Co., 14th & C Sts., N. W., Washington, D. C.
Worcester	E. T. Harrop	Fred B. Crosby, 15 Belmont St., Worcester, Mass.

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Name and Location	Chairman	Secretary
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Arizona, Univ. of, Tucson, Ariz.	C. A. Rollins	B. L. Jones
Arkansas, Univ. of, Fayetteville, Ark.	Hugh McCain	R. T. Purdy
Armour Inst. of Tech., Chicago, Ill.	A. L. Steamwedel	W. H. Sothen
Brooklyn Poly Inst., Brooklyn, N. Y.	J. C. Arnell	J. H. Diercks
Bucknell Univ., Lewisburg, Pa.	W. A. Stevens	R. J. Clingerman
California Inst. of Tech., Pasadena	W. A. Lewis	A. E. Schueler
California, Univ. of, Berkeley, Calif.	R. A. Hurley	J. M. Edwards
Carnegie Inst. of Tech., Pittsburgh, Pa.	G. L. LeBaron	H. E. Ashworth
Case School of Applied Science, Cleveland, O.	F. B. Schramm	G. J. Goudreau
Catholic Univ. of America, Washington, D. C.	K. T. Williamson	G. B. Mangam
Cincinnati, Univ. of, Cincinnati, O.	R. T. Congleton	W. C. Osterbrook
Clarkson Coll. of Tech., Potsdam, N. Y.	F. H. Porter	F. S. McGowan
Clemson Agri. College, Clemson College, S. C.	R. W. Pugh	O. A. Roberts
Colorado State Agri. Coll., Ft. Collins	S. Aldrich	F. E. Bodine
Colorado, Univ. of, Boulder, Colo.	O. V. Miller	L. E. Swedlund
Cooper Union, New York	E. J. Kennedy	A. W. Carlson
Denver, Univ. of, Denver, Colo.	Earl Reed	R. L. Kuhler
Drexel Institute, Philadelphia, Pa.	E. B. Middleton	W. N. Richards
Florida, Univ. of, Gainesville, Fla.	J. Weil	C. Washburn, Jr.
Georgia School of Tech., Atlanta, Ga.	S. M. Thomas	C. E. Burke
Idaho, University of, Moscow, Idaho	R. C. Beam	James Gartin
Iowa State College, Ames, Iowa	V. Womeldorf	G. G. Thomas
Iowa, Univ. of, Iowa City, Iowa	G. C. K. Johnson	C. A. Von Hoene
Kansas State College, Manhattan	H. M. Porter	E. J. Weeks
Kansas, Univ. of, Lawrence, Kans.	C. H. Freese	G. R. Vernon
Kentucky, Univ. of, Lexington, Ky.	R. K. Giovannoli	J. M. Willis
Lafayette College, Easton, Pa.	J. B. Powell	P. O. Farnham
Lehigh Univ., S. Bethlehem, Pa.	E. W. Baker	D. C. Luce
Lewis Institute, Chicago, Ill.	E. Millison	C. P. Meek
Maine, Univ. of, Orono, Me.	R. N. Haskell	S. B. Coleman
Marquette Univ., Milwaukee, Wis.	C. H. Legler	M. J. Smith
Massachusetts Inst. of Tech., Cambridge, Mass.	Stuart John	H. W. Geyer
Michigan State Coll., East Lansing	D. D. Miller	L. A. Traub
Michigan, Univ. of, Ann Arbor, Mich.	M. H. Nelson	S. L. Burgwin
Milwaukee Engg. School of, Milwaukee, Wis.	L. C. Eddy	E. L. Ruth
Minnesota, Univ. of, Minneapolis	R. W. Kellar	H. R. Reed
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Missouri School of Mines and Metallurgy, Rolla, Mo.	T. C. Adcock	J. D. Behnke
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Nevada, Univ. of, Reno, Nev.	Lloyd Crosby	R. C. Samuels
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North Carolina, Univ. of, Chapel Hill	H. Klingenschmitt	J. D. McConnell
North Dakota, Univ. of, University	Leo Frank	D. Donaldson
Northeastern Univ., Boston, Mass.	E. H. Barker	C. M. McCoombe
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Pittsburgh, Univ. of, Pittsburgh, Pa.	E. A. Casey	J. E. Lange
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Rhode Island State Coll., Kingston, R. I.	D. B. Brown	S. J. Bragg
Rose Poly. Inst., Terre Haute, Ind.	P. Wilkens	R. A. Reddie
Rutgers University, New Brunswick, N. J.	Stanley Hunt	S. B. Aylsworth
South Dakota State School of Mines, Rapid City, S. D.	J. V. Walrod	C. Allen
South Dakota, Univ. of, Vermillion, S. D.	C. Barret	H. Babb
Southern California, Univ. of, Los Angeles, Calif.	C. B. Little	J. Shideler
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Syracuse Univ., Syracuse, N. Y.	W. D. Johnson	W. E. Phillips
Tennessee, Univ. of, Knoxville, Tenn.	S. R. Woods	F. J. Guice
Texas A. & M. Coll., College Station	A. A. Ward	L. H. Cardwell
Texas, Univ. of, Austin, Tex.	A. A. Bown	J. B. Coltharp
Utah, Univ. of, Salt Lake City, Utah	S. W. Pixton	H. H. Tracy
Virginia Military Inst., Lexington	H. F. Watson	J. P. Black
Virginia Poly. Inst., Blacksburg, Va.	E. M. Melton	M. R. Staley
Virginia, Univ. of, University, Va.	T. M. Linville	H. M. Dixon
Washington, State Coll. of, Pullman	Tom Hunt	C. H. Backus
Washington Univ., St. Louis, Mo.	W. W. Braken	S. E. Newhouse, Jr
Washington, Univ. of, Seattle, Wash.	J. Nordahl	J. W. Lewis
West Virginia Univ., Morgantown	W. W. Mountain	J. U. Neill
Wisconsin, Univ. of, Madison, Wis.	N. G. Robisch	Stanley Roland
Yale Univ., New Haven, Conn.	E. H. Eames	F. F. Tomaine

Total 82

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies.

Ball and Roller Bearings.—Bulletins, (2), each 20 pp., describing "Norma" Precision Ball Bearings and "Hoffmann" Precision Roller Bearings, Norma-Hoffmann Bearings Corporation, Stamford, Conn.

Grounded Devices.—New Price Lists, Nos. 6 and 7 on groundulets, for water pipes and driven grounds, have been issued by the Groundulet Company, 86 Park Place, Newark, N. J.

Coil Taping Machines.—Bulletin, 8 pp., describes armature and field coil taping machines manufactured by the P. E. Chapman Electrical Works, 10th & Walnut Streets, St. Louis.

Parkway Cable.—Bulletin, 19 pp. Describes "Hazard" steel tape armored parkway cable for underground use without conduits. Hazard Manufacturing Company, Wilkes-Barre, Pa.

Oil Circuit Breakers.—Bulletin L 20253, 4 pp., describes manually and electrically operated oil circuit breakers; types D, F-1, F-2 and F-3. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Distribution Transformers.—L 20138-A, describes new type steel clad distribution transformers for single phase service on small isolated outside substations feeding from high tension lines. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Tree Wire.—New bulletin, 10 pp. Describes Hazard "Spiralweave" tree wire designed especially to overcome the sawing and rubbing effect of trees on electric light wires. Other types of "Spiralweave" cables are also described in this bulletin. Hazard Manufacturing Co., Wilkes-Barre, Pa.

Lightning Arresters.—Bulletin 1737, 16 pp. Describes the new auto-valve lightning arrester. The contents include a map prepared by the U. S. Weather Bureau, showing the average number of thunder storms per season in the United States. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Motors. Bulletin 38, 16 pp. Describes Century squirrel cage induction polyphase motors, constant speed, continuous duty, open rated, with a temperature rise not in excess of 40° C. The Century Electric Co., 1827 Pine St., St. Louis, Mo.

Static Condensers.—Bulletin L 20044-B, 4 pp., describes Westinghouse "LD" static condensers and covers the subject of losses due to low power factor, their correction, and the economic application of such condensers. Westinghouse Electric & Mfg. Company, East Pittsburgh, Pa.

Street Lighting.—Bulletin GEA-66, 12 pp., "Planning and Judging Street Lighting." Offers recommendations for the proper intensity of illumination for different classes of streets, and considers the various factors used in judging the merits of a street lighting system. General Electric Company, Schenectady, N. Y.

Transformers.—Bulletin 2047, 4 pp. Discusses polarity of Pittsburgh transformers, both single phase and polyphase, together with diagrams showing method of connecting with transformers of opposite polarity and method of determining polarity and phase rotation. Pittsburgh Transformer Company, Columbus & Preble Aves., Pittsburgh, Pa.

Magnet Wires and Varnished Insulation Material.—Catalog, in four sections, each devoted to a particular line of product, including magnet wire, special insulated wires, coil windings and varnished insulating materials. The catalog is enclosed in a loose leaf binder, so that later bulletins can be inserted, keeping the data up to date. The Acme Wire Company, New Haven, Conn.

Automatic Railway Substations.—Bulletin GEA-82, 32 pp. Includes a history of automatic stations, a general description of the apparatus, proofs of the economy of operation, scheme of operation, supervisory control, plans for apparatus arrangement and a list and illustrations and plans of typical railway installations. General Electric Company, Schenectady, N. Y.

New Westinghouse Catalog.—The Westinghouse Electric & Mfg. Company is distributing its new 1925-27 catalog of electrical supplies. The catalog presents a complete representation of the apparatus manufactured by the company, and is obtainable through its district offices or agent jobbers. The publication contains 1200 pages and is profusely illustrated with 4500 engravings, and lists all new apparatus designed and manufactured in the past two years, as well as all the previous established types.

NOTES OF THE INDUSTRY

Westinghouse Orders Increase.—According to a statement issued by the Westinghouse Electric & Mfg. Company orders received for the quarter ending June 30 last totalled $44,432,200 as compared with $40,031,000, for a similar period in 1924.

Kuhlman Electric Company, Bay City, Michigan, has appointed the Stevens Sales Company, 134 W. Second South Street, Salt Lake City, Utah, as district representatives for the state of Utah and parts of Idaho and Nevada, adjacent to Utah. The Stevens Sales Company will handle Kuhlman power, distribution and street lighting transformers.

The Roller-Smith Company, New York, announces the appointment of the Tennessee Engineering & Sales Company, 510 Burwell Building, Knoxville, Tenn., as its agents in that part of Tennessee and Kentucky, within a working radius of the city of Knoxville. J. C. Buchanan, W. L. Tadlock and S. E. Adcock comprise the personnel of the newly appointed agency, which handles the Roller-Smith line of electrical instruments and circuit breakers.

New Heavy Duty Soldering Iron.—A new soldering iron appliance which is designed for very heavy work has been placed on the market by Harold E. Trent, 259 No. Lawrence Street, Philadelphia, Pa. It is made in two styles, spear shape and hatchet type. Both of these have a copper tip in which the heating unit is clamped and which can be left on indefinitely at its rated voltage without overheating the tip or causing damage to the device.

Power Factor Correction at Machine Tool Exhibit.—The New Haven Machine Tool Exhibit, which takes place September 8-11 at the Mason Laboratory of Mechanical Engineering at Yale University will have individual static condensers installed at each motor. It was found necessary during last year's exhibit to shut off operation of some of the tools on exhibition to lighten the load, as the total current demand of the induction motors was heavier, because of low power factor, than the feeder cables would stand without overheating. The static condensers have been installed with the cooperation of the engineers of the National Electric Condenser Company, New Haven, Conn.

G. E. Employes' Bonus. Supplementary compensation to employes of the General Electric Company, totaling almost a million and a quarter dollars, was paid the past month at all the factories and offices of the company. The actual amount paid was $1,247,496, and the number of employes of the company participating in the disbursement 29,558.

The payments cover the six months which ended June 30, and are being made only to those employes who have five years or more of continuous service with General Electric. The amounts paid to each individual constitute five per cent of the individual's earnings during the period covered.

Both the total amount paid and the total number of employes is considerably larger than the corresponding items for the last previous six months.